THE DIVERSITY, DISTRIBUTION AND FEEDING BEHAVIOR OF SOLIFUGES (ARACHNIDA; SOLIFUGAE) IN KENYA

A Thesis

by

KRISTIE LYNN REDDICK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2008

Major Subject: Entomology

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Approved by:

Chair of Committee,	Robert Wharton
Committee Members,	James Woolley
	Ronald Zellner
Head of Department,	Kevin Heinz

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ABSTRACT

The Diversity, Distribution and Feeding Behavior of Solifuges (Arachnida; Solifugae) in Kenya. (May 2008)

Kristie Lynn Reddick, B.F.A., University of the Arts

Chair of Advisory Committee: Dr. Robert Wharton

Little is known of the diversity of solifuges in East Africa or their habitat preferences and feeding biologies. A survey was undertaken to improve our understanding of the diversity and distribution of solifuges in Kenya and these data were supplemented by the solifuge holdings of the National Museums of Kenya (NMK), which were identified as part of this study. Historical records of each species found during this survey were verified through assessment of the primary literature and distributions were mapped for all Kenyan spp. A feeding study was conducted to determine preference between hard and toxic prey, and owl pellets from Tucson, Arizona were dissected to determine the importance of solifuges as prey. Finally, various outreach activities that were led and organized during this study were discussed, detailing the importance of science outreach as the bridge between research and the general public.

All solifuges used in the feeding study ate the termites that were used as a behavioral control, but only three individuals of one species of solifuge, *Z. fordi*, were able to eat both hard and toxic prey items repeatedly. Solifuges were more willing or

able to eat toxic prey than hard. Burrowing owl pellets from Tucson, Arizona were examined for invertebrate parts and preference was assessed for the five most commonly eaten arthropods. Solifuges were the third most frequently encountered arthropod in the pellets, after caterpillars and beetles, and were also the third most abundant.

Solifuges were sampled over a period of six months and collected from 28.V.2006-8.VI.2006 and 11.II.2007- 13.V.2007 from eight different localities in Kenya. During this survey two genera were newly recorded for Kenya, *Tarabulida* and *Solpugyla*. In addition, the *Tarabulida* specimen is the first male ever recorded for the genus. Three new species records for Kenya were added: *Z. sericea, Z. lobatula* and *Z. meruensis,* and six undescribed species were recorded from Kenya as a result of this survey, including five unidentified rhagodids and species of *Tarabulida*. The southernmost locality record for the Galeodidae and *Galeodes arabs arabs* was uncovered in the NMK holdings.

DEDICATION

I dedicate this thesis to my grandmother, Hildegard Finkenstat Oberhofer. She is 93 years old, was the first female air-traffic controller, and still has more energy than most people my age. She gave me a loan to go back to school, so I could take a biology course at a community college. It was my first step toward a full career change, and without that loan, I would have never discovered solifuges and my love for Kenya.

ACKNOWLEDGEMENTS

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Asante sana to my affiliates and colleagues in Kenya: Dr. Charles Lange, Head of the Invertebrate Division of the Zoology Department of the National Museums of Kenya, for allowing me to conduct research in affiliation with the museums; Dr. Charles Warui, my advisor in Kenya, for his advice and knowledge of field-work in Kenya and his logistical support; and finally, Mr. Joseph Mugambi, head research assistant for the Invertebrate Division, and my constant companion in the field. There are no words to express how privileged I am to have worked with Mugambi. Without him, I would surely be dead, many times over. Thank you also to the Kenya Wildlife Service for

granting me access to national parks and reserves in Kenya, their interest in the project and their support in fending off wild animals at night.

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There are myriad people who have helped in big and small ways throughout my thesis program and I mention them here. Thanks to Ed Riley for help with identification of arthropod parts from owl pellets, Don Thomas from the USDA lab in Weslaco for help with tenebrionid questions, Aaron Dickey for his help with GIS, Anderson Tuitoek for his incredible field-skills, Dr. David Harper and his wife for their hospitality and for buying my truck, and Jacob Kabichiri for taking such good care of my truck and teaching me how to drive that tank. Thanks to Jackson Komen for collaboration on workshops for the Lake Bogoria National Reserve Dryland Environmental Education Center, and William Kimosop, the warden of the reserve, for support of this project, his interest in arachnids, and his inclusion of solifuges into the management plan of the

park. Thanks to the entire Upper Hill Campsite staff for their incredible hospitality during my six months in Kenya.

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Last but not least, a special thanks to Jessica Honaker. Thank you for trusting me with your future, for braving hyenas and riots, and for helping to make my adventure unforgettable.

NOMENCLATURE

AMNH	American Museum of Natural History
AZGFD	Arizona Game and Fish Department
KWS	Kenya Wildlife Service
NMK	National Museums of Kenya

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CHAPTER I

INTRODUCTION: THE IMPORTANCE OF RESEARCH

Solifuges, often called camel-spiders, wind-scorpions or sun-spiders, are ancient arachnids that trace back to the Carboniferous Period (Harvey 2002b). Solifuges are most closely related to the pseudoscorpions (Class Arachnida, Order Pseudoscorpionida) and comprise only 1.1% of the known species of arachnids (Shultz 1989; Harvey 2002a). There are over 1075 described species of solifuge in the world, representing 12 families (Maury 1985; Punzo 1998; Harvey 2003) and these have recently been catalogued (Harvey 2002a, 2003). In the past few years, there has been renewed interest in this group of arachnids in part because of anecdotal tales from the Gulf War that have fueled stories of excessive size, aggression, bizarre feeding habits and venomous bites.

In general there is very little known about solifuges, with detailed biologies published on less than a dozen species (Heymons 1902; Lawrence 1947, 1949; Amitai et al. 1962; Muma 1974a, 1966 a-d; Junqua 1966; Cloudsley-Thompson 1967, 1977; Wharton 1987; Muma & Muma 1988; Punzo 1998). Despite the fact that much of the biological information available about solifuges is based on anecdotal evidence, there is general agreement that solifuges prefer arid/semi-arid habitats in the tropical, subtropical and temperate regions of the world (Muma 1976, 1982; Cloudsley-Thompson

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This thesis follows the style of the Journal of Arachnology.

1977,1984). Arid lands are characterized by receiving an average annual rainfall of up to 350 mm. Semi-arid zones get less than 700 mm of rainfall annually (Middleton 1997). The only quantitative studies focused on habitat preferences were conducted in southern Africa by Wharton (1981) and Griffin (1990) and in the southwestern United States by Muma (1974a/b).

The available information on solifuge biology has been reviewed by Muma (1966a, 1966b, 1967), Cloudsley-Thompson (1967, 1977), Muma & Muma (1988) and Punzo (1998). Early functional morphology studies, comparing solifuges with other arachnids, were done by Bernard (1892, 1893a/b/c/d, 1894a/b, 1895, 1896). Most of his comparative work focused on the Galeodidae. Although complete life cycle information is not known for any of the species, detailed life history data have been published for species such as the galeodids *Othoes saharae* Panouse, 1960 (Junqua, 1966) and *Galeodes granti* Pocock, 1903 (Cloudsley-Thompson 1961a/b, 1967), the eremobatids *Eremobates durangonus* Roewer, 1934 (Muma 1966c), *E. mormonus* Roewer, 1934 and *E. marathoni* Muma, 1951 (Punzo 1995, 1998), and the solpugid *Metasolpuga picta* Kraepelin, 1899 (Wharton 1987). Muma (1966a, 1966b) completed extensive work on North American Solifugae, covering feeding behavior for 18 species and burrowing habits of 10 species.

Mating behavior in solifuges has been described for several species and for the most part is uniform with minor variations (Amitai *et al* 1962; Cloudsley-Thompson 1967). Males use their pedipalps to coerce the female into a 'frozen state' or torpor and use their chelicerae for positioning of the female and for sperm transfer. More specifics

about the subtle differences between mating behaviors of solifuges are needed to determine if mating behavior differs among solifuge families. The flagella, on the chelicerae, is a structure unique to the solifuge. All male solifuges, except for those in the family Eremobatidae have flagella on the chelicerae and they are thought to play a role in the establishment of territories during the mating phase (Lamoral 1974). They vary greatly within families and between species, ranging from long and whip-like, to plumose bristles, to small flaps of cuticle extending from the chelicerae (Roewer 1932 (1933, 1934). The flagellum is believed to have arisen from setae on the chelicerae. Often, the flagellum is the only reliable characteristic for identification of solifuges (Roewer 1934). No recent experiments have been conducted to find the exact function of these structures.

Egg-deposition has been observed for several species including *Zeria* (formerly *Solpuga) caffra* (Pocock, 1897) (Lawrence 1949), *Galeodes granti* Pocock, 1903 (Cloudsley-Thompson 1967), and *Metasolpuga picta* (Wharton 1987). Egg-deposition and incubation by *Eremobates durangonus* was observed over a two-year period by Muma (1966c). Several other species were observed to have laid eggs, but *E. durangonus* was the most successful under laboratory conditions. Eggs of *E. durangonus* were laid in masses of 20-164 eggs an average of 11.3 days after mating. Lawrence (1947) observed the eggs and first instars of *Solpuga hostilis*, and found them markedly different from Roewer's (1934) interpretations of newly hatched *Galeodes* Oliver, 1791. The biggest difference was the presence of thick, long setae of the larvae

of *Solpuga* Lichtenstein, 1796. Lawrence hypothesized the setae to function as an aid in egg hatching, and suspected that setae would be shed after the first molt.

The behavior of burrowing has been described several times (Muma, 1966a; Cloudsley-Thompson 1977; Gore & Cushing 1980; Wharton 1987). Burrows provide humidity and protection from extreme temperatures and predators. Gore & Cushing (1980) determined that the behaviors of male and female *Ammotrechula penninsulana* (Banks, 1898) were markedly different. Males are more likely to construct shallow burrows beneath rocks and debris, while females are more likely to construct deeper "tube" burrows. They concluded that males reuse burrows for three days and restricted themselves to temporary foraging near the burrows due to the large energy expenditure of constructing a burrow. Females did not return to a burrow, even though they were deeper and took more energy to construct. This is perhaps because females use vacated burrows of other animals to conserve energy for egg-production. This dimorphism of burrow construction has not been examined in other species of Solifugae.

Feeding behavior of solifuges has most often been recorded anecdotally (Punzo, 1998) with a few observations made during other work (Wharton 1981; Lawrence 1949, 1963; Muma 1966b, 1982). Solifuges have several interesting structures not found on other arachnids, such as malleoli and suctorial organs thought to aid in prey detection and capture. Racket organs, or malleoli, are fan-shaped organs on the ventral surfaces of the hind legs. Extensive work on the structure of these organs in *Galeodes arabs* Koch, 1842 has been completed and while the function is still not entirely clear, they are believed to have chemosensory properties and respond to substrate vibrations possibly

aiding to locate prey beneath the surface (Brownell & Farley 1974; Wharton 1987). Another organ that may aid in prey location and capture are the adhesive organs on the ends of the pedipalps, called the suctorial organs (Cushing *et al.* 2005). By observing climbing habits, and using a combination of microscopy, photography and video of the palpal organs Cushing *et al.* (2005) were able to determine the function of the organ in prey capture and climbing. Wharton (1987) also observed *M. picta* females occasionally using their palps to bring food closer to the chelicerae. These suctorial organs are responsible for the large numbers of solifuges that escape from dry pitfall traps during surveys (Muma 1975a/b).

In addition to the general lack of information about solifuge feeding habits, abilities and preference, there is no understanding as to how solifuges fit into desert food webs as a source of food for vertebrates and invertebrates alike. There are singular records of species that eat solifuges, but to date, never has a study focused on solifuges as prey.

One of the most interesting questions with regard to solifuges is the geographical pattern of diurnal behavior. Cloudsley-Thompson (1977) stated that most solifuges are nocturnal with a few exceptions. In most parts of the world, there are apparently few diurnal species, but in southern Africa, a significant proportion of the species in the large family Solpugidae are reputedly diurnal (Lawrence 1963; Wharton 1981). Wharton's (1987) comparison of the biology of the diurnal *M. picta*, a large solpugid from Namibia, with nocturnal species includes some of the only work on solifuge thermoregulation and

observations on foraging, mating, burrowing habits, oviposition, and intraspecific aggression of diurnal species.

Some of the most important taxonomic works on solifuges are the monographs of Kraepelin (1899) and Roewer (1934) and the revisions by Lawrence (1960, 1962, 1963 1968, 1972), Muma (1951, 1976, 1982) and Muma & Muma (1988). While Roewer's work is the most comprehensive modern treatment, there are discrepancies in characters used to delineate genera and species, and a revision is necessary (Muma 1976; Lawrence 1967a; Wharton 1981). Muma (1976, 1982) reviewed the Solifugae at the family level, providing succinct descriptions of all 12 families with reworked family key. Harvey (2002a) made extensive nomenclatural changes that have far reaching implications for most families. Most of the recent work on solifuges has been restricted to North American, South American, and South African species, with a focus on galeodids, eremobatids and ammotrechids (Wharton 1987). Subsequent to Roewer, very limited work has been completed on solifuges from North Africa, the Middle East and Asia. This work is not at all comprehensive and generally focuses on a limited number of species (Kraus 1959; Gromov 1998, 2000; Thaler 1982).

The most thorough recent taxonomic work on solifuges is for the North American species (Muma 1951, 1962, 1976, 1982; Muma & Muma 1988; Rowland 1974). There has also been some work on South American solifuge species (Maury 1980, 1981, 1982a/b, 1983, 1984, 1985; Kraus 1966; Muma 1971; Rocha & Cancello 2002). Of particular interest is the presence of Daesiidae in South America as well as Africa, Spain and the Near East (Roewer 1934). Maury (1980, 1981, 1982a, 1983)

contends that Daesiidae are found in South America based on his placement of *Syndaesia mastix* Maury, 1980 in this family. The occurrence of Daesiidae in South America was initially overlooked due to the unfamiliarity of New World specialists with Old World fauna, pointing to the importance of revising all Solifugae from a world perspective

To date there has been a great deal of work on southern African solifuges (Simon 1888; Hewitt 1914; Fage 1923; Kraus 1956; Roewer 1934; Lawrence 1927, 1929, 1935, 1938, 1945, 1955, 1960, 1961, 1962, 1963, 1964, 1966, 1967a/b, 1968, 1972; Junqua 1966; Della Cave & Simonetta 1971; Della Cave 1978, 1979; Wharton 1981). Most of the work has been done on species from Namibia and South Africa (Lamoral 1972, 1973; Wharton 1987). Wharton (1981) revised several of Roewer's and Lawrence's original descriptions for all of the species in Namibia, providing the most comprehensive work on southern African solifuges to date. Lamoral (1973) described solifuges from Kalahari Gemsbok National Park. He concluded that a lack of proper collecting in the Kalahari Desert had prevented more species than the 30 on record from being discovered and the same could be said about Kenya.

Kenya, and other parts of eastern Africa, have been largely ignored during solifuge surveys, and except for specimens deposited at various museums in Europe and Kenya, there is very little known about the diversity and distribution of solifuges in Kenya. Most specimens described were the result of by-product of surveys targeting other animals, and to date there has never been a targeted survey for solifuges in the region. By collecting in the region, we can contribute to overall knowledge about

solifuges in East Africa. Also, observations of feeding, both in the field and under lab conditions, will help to broaden knowledge of solifuge feeding habits. The objectives of this study are as follows:

1. To conduct the first survey of Kenyan solifuges, based on specimens newly collected as part of the thesis and uncataloged museum holdings.

This objective includes, as sub-objectives, the testing of two hypotheses:

a. To test the hypothesis that Kenya represents a region of overlap between solifuge families occurring in northern Africa and those known only from southern Africa.

b. To test the hypothesis that diurnal solifuges are largely restricted to southern Africa and thus would be rare or absent in Kenya.

2. To determine solifuge preference for and ability to eat hard and toxic prey.

3. To assess the role of solifuge as prey in desert ecosystems through quantification of arthropod remains from burrowing owl (*Athene cunicularia* Molina, 1782) pellets.

4. To demonstrate that outreach, especially in underserved parts of the world, can be a bridge between scientific research and the general public.

CHAPTER II

DIVERSITY AND DISTRIBUTION OF SOLIFUGES IN KENYA

INTRODUCTION

Twelve families of Solifugae are distributed across every continent except Australia and Antarctica. Eight families (Ceromidae, Galeodidae, Gylippidae, Hexisopodidae, Karschiidae, Melanoblossidae, Rhagodidae and Solpugidae) are found solely in the Old World (Fig. 1). Three (Ammotrechidae, Eremobatidae and Mummuciidae) are found solely in the New World. Only one family, Daesiidae, is found in both. The majority of daesiids are found in Africa, Asia and southern Europe, (Harvey 2003) but there are three monotypic genera described from Chile and Argentina by Maury (1980, 1981, 1985). Eremobatids and ammotrechids are found throughout North America, Mexico and Central America, with ammotrechids extending further down into South America and to the Caribbean Islands. Mummuciidae are found throughout South America. Most gylippids are recorded from the Middle East and Asia, but there are six species described from Namibia and South Africa (Wharton 1981) (Fig. 2). The large gap in distribution of gylippids in central and east Africa could point to a lack of collecting. Ceromidae are mainly found in southern Africa, but several species of the genus *Ceroma* extend up through the Democratic Republic of the Congo, Malawi, Uganda, Tanzania and Kenya (Fig. 3). Hexisopodidae are thought to be restricted to isolated pockets in southern Africa, but one species, *Chelypus macroceras* Roewer, was recorded as far north as Zambia. The melanoblossids are restricted to southern Africa

Fig. 1: Map of Africa with Country Names (Kenya highlighted).

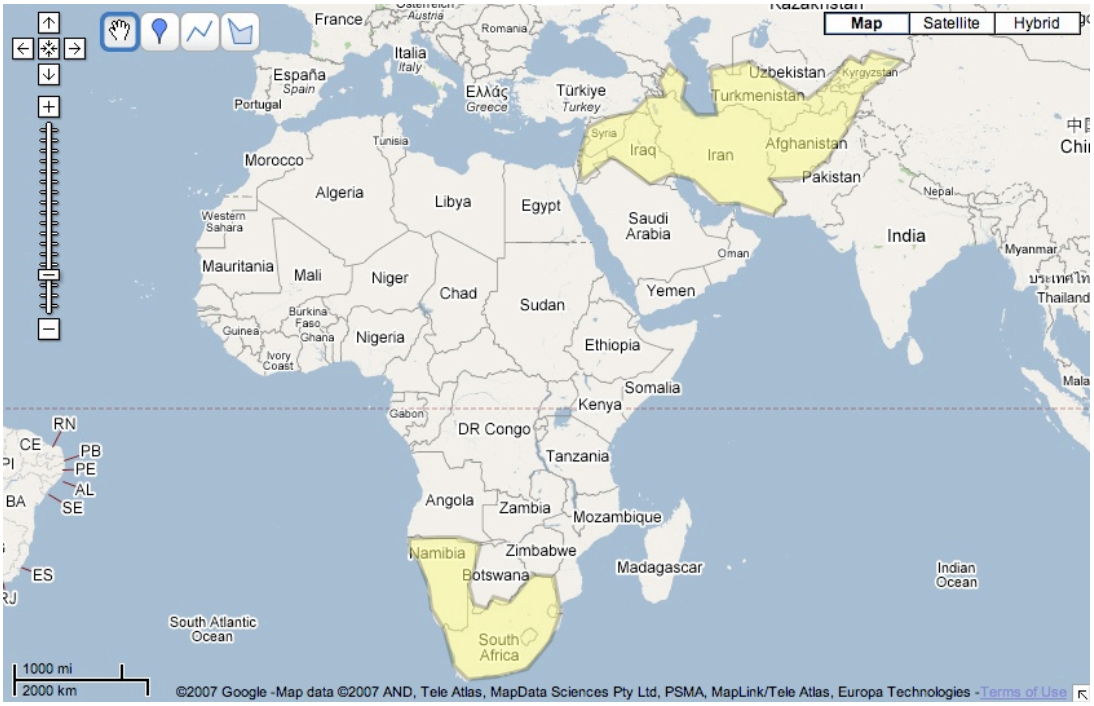

Fig. 2: Distribution of Gyllipidae.

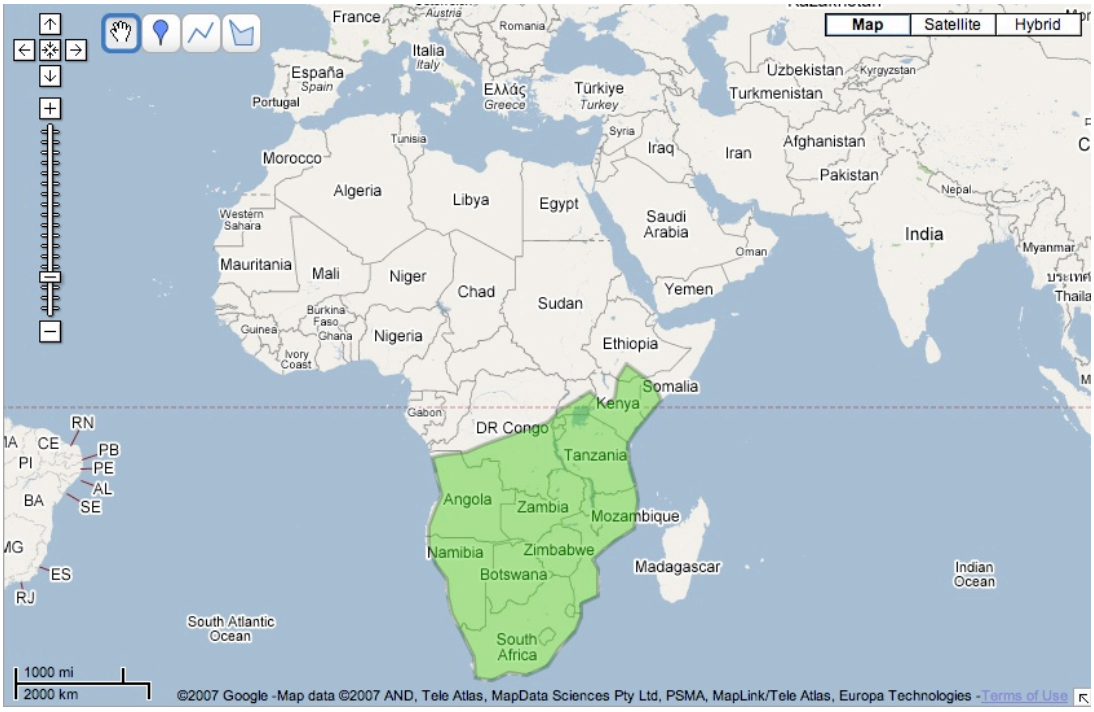

Fig. 3: Distribution of Ceromidae.

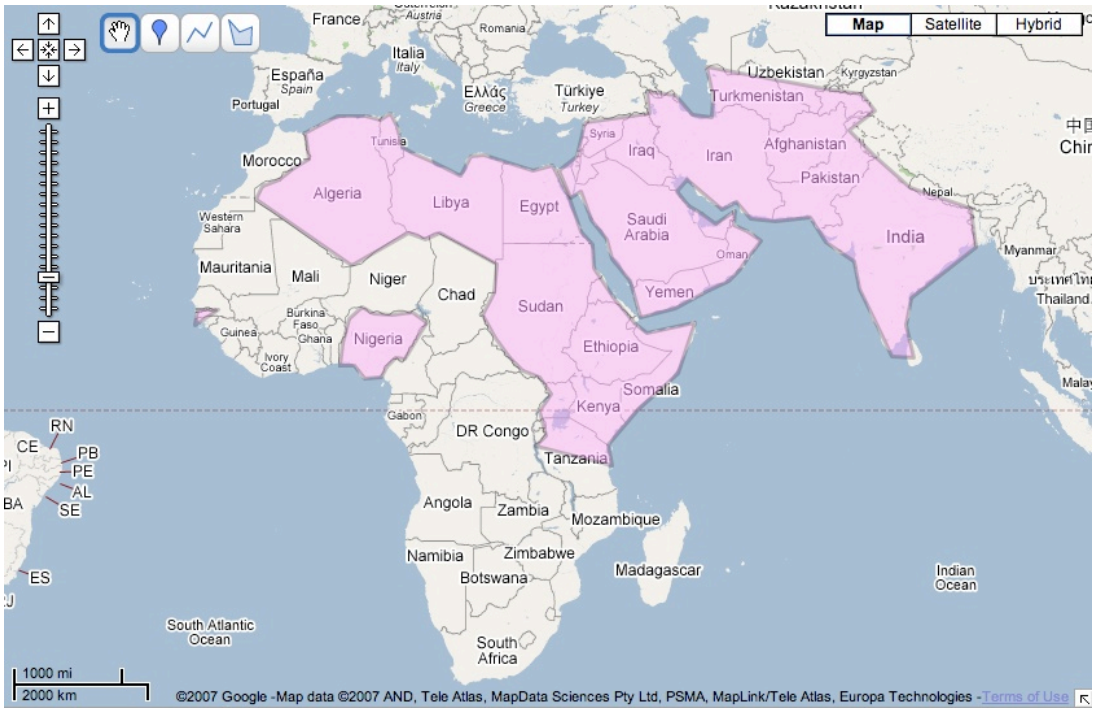

Fig. 4: Distribution of Rhagodidae.

with one genus, *Dinorhax*, found in Indonesia in South-East Asia. The Karschiidae are found from Greece to the Middle East and China. Rhagodids extend mainly from the Middle East south to Sudan, with several species of the genus *Rhagodoca* extending into Kenya and two species from the genus *Rhagodes* recorded from Tanzania (Fig. 4). The Galeodidae are distributed in the Middle East, Asia and North Africa, with several species extending to Ethiopia and Sudan, border countries of Kenya. One species, *Galeodes arabs arabs*, is recorded from Kenya. The Solpugidae are widely distributed throughout all of Africa and into the Middle East.

Kenya is in an interesting position biogeographically, as it lies at the southern end of the range for families that occur in northern Africa, and at the northern end of the range for families that occur in southern Africa. There has never been a targeted survey of solifuges in Kenya, and while there have been species collected in the country, they were the accidental by-product of surveys targeting other arthropods. Thus, there is great potential for discovering a highly diverse fauna. There are 36 species recorded from Kenya, including 7 formally described subspecies (Table 1).

Table 1: Species of solifuges recorded from Kenya prior to this study.

Family	Genus	Species	Author
Ceromidae	*Ceroma*	*ornatum*	Karsch, 1885
Daesiidae	*Blossia*	*toschii*	(Caporiacco, 1949)
	Biton	*brunnipes*	Pocock, 1898
		tigirinis	Pocock, 1898
		velox dmitrievi	(Birula, 1905)
		velox velox	Simon, 1885
	Bitonupa	*kraepelini*	Roewer, 1933
	Hemiblossia	*bouvieri*	Kraepelin, 1899
		brunnea	Lawrence, 1953
Galeodidae	*Galeodes*	*arabs*	Koch, 1842
Rhagodidae	*Rhagodoca*	*baringona*	Roewer, 1933
		bettoni	Roewer, 1933
		immaculata	Roewer, 1933
		ornata ornata	(Pocock, 1895)
		ornata tenebrosa	Lawrence, 1953
		phillipsii	(Pocock, 1896)
		smithii	(Pocock, 1897)
		termes	(Karsch, 1885)
Solpugidae	*Solpuga*	*roeweri majora*	Lawrence, 1953
		roeweri roeweri	Fage, 1936
	Solpugiba	*svatoshi*	(Birula, 1926)
	Solpugisticella	*kenyae*	Turk, 1960
	Zeria	*capitulata*	(Karsch, 1885)
		fordi	(Hirst, 1907)
		loveridgei	(Hewitt, 1925)
		merope	(Simon, 1879)
		nasuta	(Karsch, 1880)
		niassa	(Karsch, 1880)
		nigrescens	(Pocock, 1895)
		obscura	(Kraepelin, 1899)
		sulfuripilosa	(Roewer, 1933)
		wabonica	(Roewer, 1933)
		zebrina	(Pocock, 1898)
	Zeriassa	*bicolor*	(Pocock, 1897)
		inflexa fuchsi	Lawrence, 1953
		intermedia	Lawrence, 1953
		ruspolli	(Pavesi, 1897)
		spinulosa	Pocock, 1898
		wabonica	Roewer, 1933

There are 82 species recorded from countries bordering Kenya and any or all of these might be found in Kenya. These include 5 species of Ceromidae (1 genus), 15 species of Daesiidae (6 genera), 11 species of Galeodidae (5 genera), 25 species of

Rhagodidae (9 genera), and 26 species of Solpugidae representing 6 genera (Harvey 2003).

This survey addresses three main questions with regard to solifuges in Africa. Is Kenya an important overlapping ground for families in the north and south of the continent? Are there new or different species that have not previously been recorded in Kenya? Are there diurnally active solifuges in Kenya and if so, do they belong to genera or species groups known to be diurnally active elsewhere? There is speculation that diurnal behavior of solifuges is restricted to southern Africa, however collecting efforts have been extremely limited in the area between South Africa and Sudan. It is possible that diurnal behavior is exhibited in solifuges in East Africa because several genera of Solpugidae that have diurnal species in southern Africa have been recorded from Kenya and Tanzania. In collecting solifuges for this objective, a more comprehensive understanding of the distribution of solifuges in Kenya will be obtained.

This work will form the basis for a larger, more long-term collaborative effort on African Solifugae.

MATERIALS AND METHODS

Study Area

Due to social and political unrest in Northern Kenya along the borders of Somalia and Sudan, this project concentrated on areas from Mt. Kenya, west to Kitale, south along the border of Tanzania to Garissa in the east, except for five collecting days spent along the Sudan/Ugandan border in Lokichoggio Township, northwestern Kenya.

Sites were chosen based on the high percentage of arid/semi-arid lands and reflect as many different habitats in southern Kenya as possible. Sampling took place over a six month period but solifuges were only collected over a period of approximately 3.5 months, from 28.V.2006-8.VI.2006 and 11.II.2007- 13.V.2007 from 8 different localities: Arabuko Sokoke Forest, Kimana Township, Lake Baringo National Reserve, Lake Bogoria National Reserve, Lokichoggio Township, Maasai Mara National Reserve, Nairobi Town and Tsavo West National Park. Other areas were sampled where solifuges were not collected: Hell's Gate National Park, Ologesaillie, Lake Naivasha, and Ngong. The following information on these sites is from the Kenya Wildlife Service (2007).

Arabuko Sokoke National Forest is a large remnant coastal forest approximately 110km north of Mombasa. Solifuges were collected from the mixed forest habitat that dominates the eastern side of the reserve. The soil in this area is grey sand and characteristic trees in this section of the forest include *Combretum schumannii* Engl., *Drypetes reticulata* Pax, *Afzelia quanzensis* Welw., *Dialium orientale* Bak.f., *Hymenaea verrucosa* Gaert. and *Manilkara sansibarensis* (Engl.) Dubard (Birdlife International 2007).

The Kimana Wildlife Sanctuary in southern Kenya is located between Tsavo West National Park and Amboseli National Reserve. It is 40 km^2 (Okello 2005). Solifuges collected here were found under rocks at the base of small kopjes, rocky islands in the middle of savannah grassland.

Lake Baringo is a large freshwater lake located in the north Rift Valley. Solifuges were collected in an area west of the lake on red, hard clay soils under small rocks. The area immediately surrounding the lake is largely desert scrubland.

Lake Bogoria National Reserve is 107 km^2 (UNESCO 2007) located on the west side of the Great Rift Valley, north of Hell's Gate National Park. Lake Bogoria is a shallow alkaline lake and is surrounded by sulfur geysers, dry bush and rocky grassland. Near the shore of the lake the soil consists of stratified deltaic silts and saline deposits (Kimosop 2007). Away from the shore, the dominant soil types are clay soil and silt loam. On the banks of riparian areas in the reserve the dominant soil type is clay loam. The reserve and surrounding areas are dominated by small hills and rises covered in volcanic rocks dating to the Pleistocene and Meiocene eras (Kimosop 2007) (Fig. 5).

Lokichoggio Township is located approximately 30 km from the Sudan border in northwestern Kenya. Solifuges found in this area were collected from under rocks in shallow depressions in a dry riverbed and at the base of the Mogilla Range, a fault accumulation made up predominantly of trachyte, rhyolite and associated tuffs (Champion 1937).

Maasai Mara National Reserve and Conservancy Area is an extension of Tanzania's Serengeti ecosystem in southwestern Kenya. The Mara is 392 km^2 with altitudes ranging between 1500-2180m. The soil is predominantly black-cotton, and the Mara is predominantly savannah grass plain with dispersed *Acacia spp.* woodlands. Arid grasslands have proven to be an ideal habitat for solifuges elsewhere (Muma 1974a).

One solifuge was collected from inside the city limits of Nairobi. It was found at night in a yard running toward lights.

Tsavo West National Park is located in southeast Kenya in the Kajiado District and is the largest plot of protected land in Kenya at 9000 km^2. The altitude ranges from 200-1000m. The Tsavo ecosystem is dominated by *Acacia-Commiphora* bush and desert scrub, preferred habitat for solifuges (Punzo 1997). The Shetani Lava Flow is a 200-year old geological formation composed almost entirely of sharp, black volcanic rocks (Fig. 5). The Chyulu Hills, in the south of the park, is an isolated ecosystem of grassland and dry forest on volcanic hills and solifuges have been observed in the area.

Collecting Methods

Solifuges were collected by hand using several different methodologies. Most were found in shallow burrows under large stones that were rolled during the day. Deeper burrows were excavated when necessary. Diurnal solifuges were located in Lake Bogoria National Reserve and Tsavo West National Park's Shetani Lava Flow by visiting areas of black volcanic rocks between 10am and 3pm. Diurnal solifuges were caught by hand after observing them running on black volcanic rocks between these times. In areas where night collection techniques could be used safely, such as Arabuko Sokoke National Forest and Lake Bogoria National Reserve, gas lanterns and stoves were used to attract solifuges.

In addition to specimens collected in the wild, the solifuge holding from the National Museums of Kenya, Nairobi (NMK) were also examined. In total, 234 solifuges from NMK were examined as a part of this study.

Fig. 5: Shetani Lava Flow, Tsavo West National Park, Kenya.

Specimen Repository

All specimens collected in Kenya during this study will be deposited in NMK except for duplicates of common species (as indicated in the species treatments below), which will be deposited in American Museum of Natural History, New York, USA (AMNH).

Specimen Identification

All specimens collected in Kenya during this study were identified using a variety of keys. Since the NMK solifuge collection was largely unidentified, authoritatively determined material was not available for comparison. Roewer (1934), Muma (1976), Wharton (1981), Punzo (1998) and Harvey (2003) have provided keys to families and family-level identification is generally not difficult except for some of the smaller immatures. Identification to genus and to species is fraught with difficulties because the only available keys that cover Kenya are those by Roewer (1934) for the world fauna. Roewer's keys rely heavily on adult males, and have been criticized by many workers (Muma 1976; Wharton 1981; Punzo 1998) because of the use of intraspecifically variable characters to define some of the genera. It is for this reason that females and immatures were grouped into morpho-species. Females and immatures were identified to species only when there were associated males found in the same area and habitats.

The NMK collections were also identified using all available keys. However, because of the large span of time over which the collection has been accrued, by many different collectors, there was not enough data to accurately associate females and immatures, therefore only males could be positively identified.

Mapping

Maps presented in this paper were generated using Google Maps and ArcGIS 9.1. Latitude and longitude for all museum and historical data were found using http://www.satsig.net/maps/lat-long-finder.htm to the nearest approximation. A

handheld GPS was used for all sampling sites in Kenya; latitude and longitude were recorded in UTM. All published localities were verified from original sources, where possible, since only country records and type localities are included in Harvey's (2003) catalog, and some subsequent citations proved erroneous. Where localities could not be verified, or where place names (other than countries) have undergone changes since the original publications, these are indicated. On the maps, blue squares indicate historical records, green circles indicate NMK records, and red triangles indicate new records from solifuges collected during this targeted survey.

RESULTS

Species Treatments

The following species were collected during this study or found in NMK holdings.

Ceromidae

The distribution of *Ceroma ornatum* Karsch, 1885 is shown in Fig. 6.

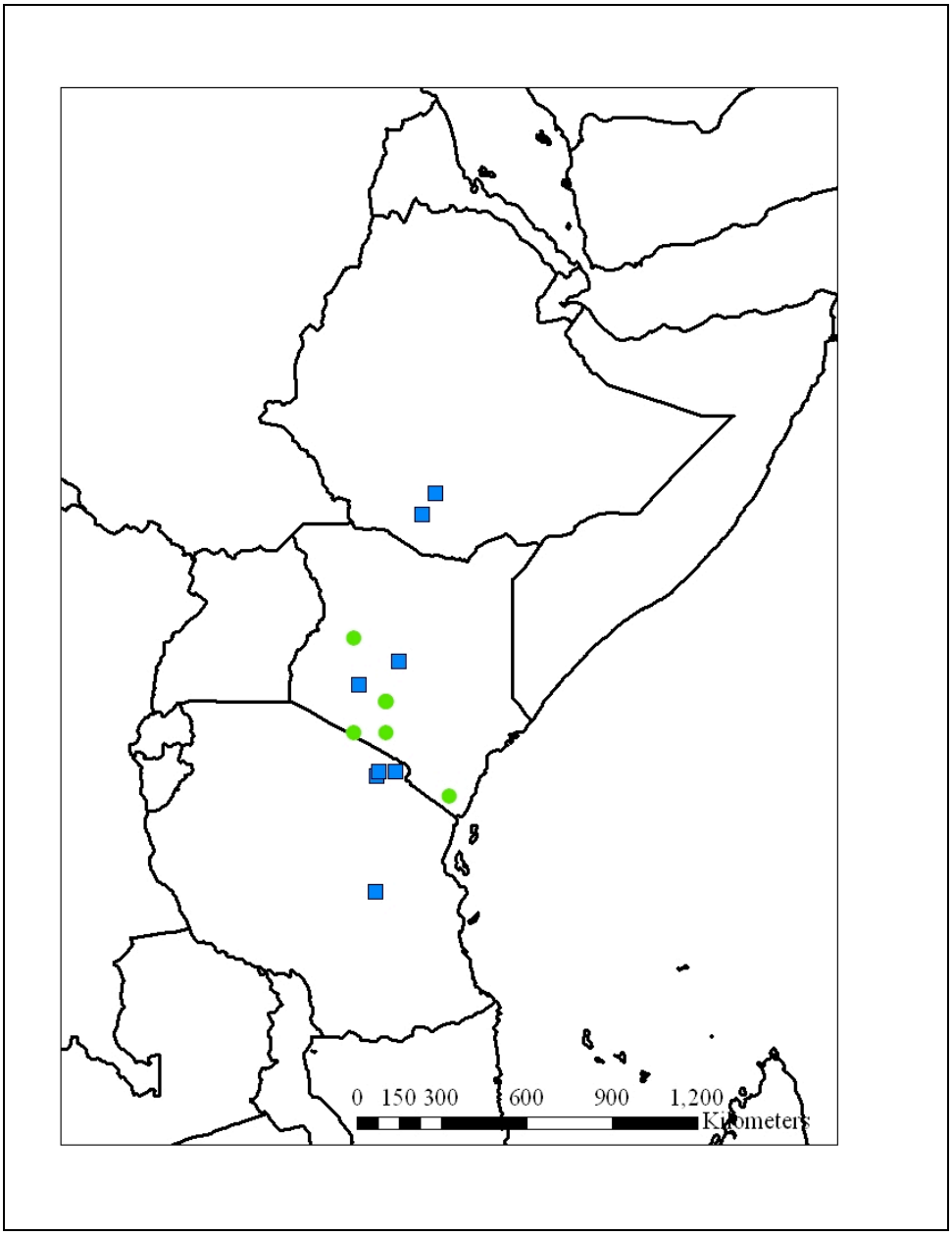

Fig. 6: Distribution of *Ceroma ornatum*. (Notes on country records listed below)

ETHIOPIA: Sidamo Province, Borana (formerly Javello)(Simonetta & Delle Cave, 1968), Giari Bule (Pavesi 1897; Birula 1926; Simonetta & Delle Cave 1968).

KENYA: Central Province, Kabete, XI.1970, 1 male (NMK); Coast Province, Mackinnon (Caporiacco 1949); East Province, Athi River, VII.1970, 1 male (NMK), Lukenya (Athi River), XI-XII.1971, 1 male (NMK); Nairobi Province, Nairobi, (Caporiacco 1949), Nairobi, Langata, 26.IV.1987, 1 immature (NMK), Karen Mbagathi Ridge, 9.XI.1982, 1 male (NMK); Rift Valley Province, Cherangani Hills, 27.VIII.1968, 1 male (NMK), Elementaita (Caporiacco 1949), Olorgesailie, 14.VI.1980, 1 male (NMK), Samburu (Pocock 1898).

TANZANIA: Arusha Area, Ebene (Karsch 1885); Kilimanjaro Area, Kibonoto (Tullgren 1907), Mt. Gurui (Kraepelin 1901); Mt. Meru area, lowlands (Tullgren 1907).

UGANDA: No specific locality (Harvey 2003).

Remarks

Moriggi (1941) identifies Giari Bule as a location in Somalia, however the location is in Ethiopia as stated above. Although there are several records for *Ceroma ornatum* from the NMK holdings found in and around the Nairobi Highland areas, none were collected during this targeted study. The identity of these specimens was confirmed as *ornatum* by examining the flagellum length in relation to the eyes and color patterns.

Diel Periodicity and Habitat Preference

Ceromids are notoriously hard to collect and therefore are the least studied solifuges. Nothing has been written about their habitat preferences. Since these specimens were in the NMK holdings, no additional information can be offered on diel periodicity or habitat. Previous workers have simply recorded localities with no additional habitat information.

Daesiidae

The distribution of *Biton tigrinus* Pocock, 1898 is shown in Figure 7.

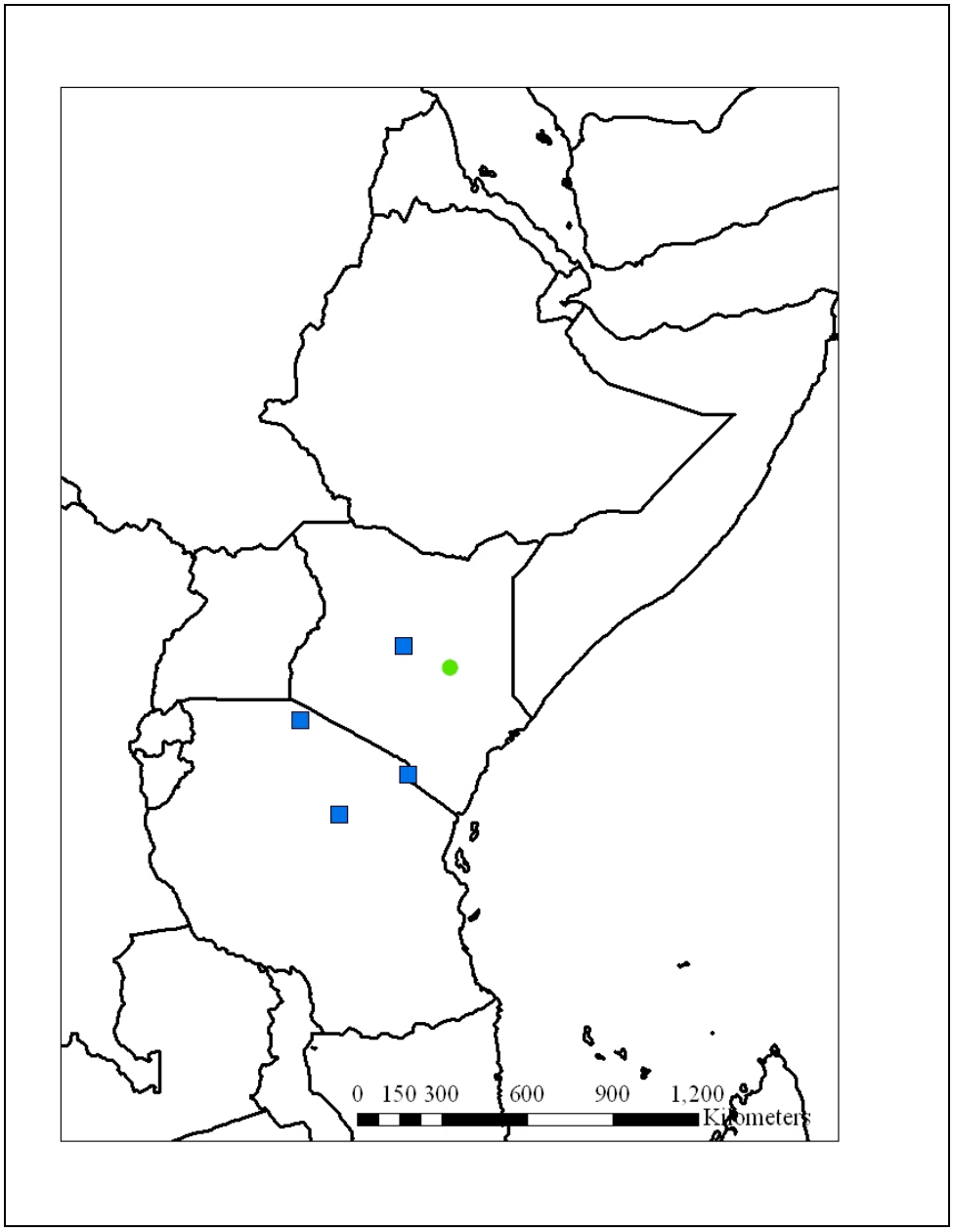

Fig. 7: Distribution of *Biton tigrinus*. (Notes on country records listed below)

KENYA: Coast Province, Taveta, Ziwani (Birula, 1926); Rift Valley Province, Samburu (Pocock 1898); Uaso Nyiro River, nr. Laikipia, 23.X.1976, 1 male (NMK)

TANZANIA: Tabora area, Mangati, Iramba (Kraepelin 1901)

Remarks

Pocock (1898) described *Biton tigrinus* from a specimen collected in the Rift Valley, near Samburu. Pocock acknowledges that the 4th legs of the specimen were missing and this might affect its generic placement. However, Kraepelin (1901) and Birula (1926) redescribed *B. tigrinus* based on additional, presumably more intact, material. The NMK specimen found during this survey is most definitely a *Biton*.

Diel Periodicity and Habitat Preference

The only specimen examined during this survey was identified from the NMK holdings, and there is no information as to its activity patterns or habitat preference.

Daesiidae

The distribution of *Biton velox velox* Simon, 1885 is shown in Figure 8.

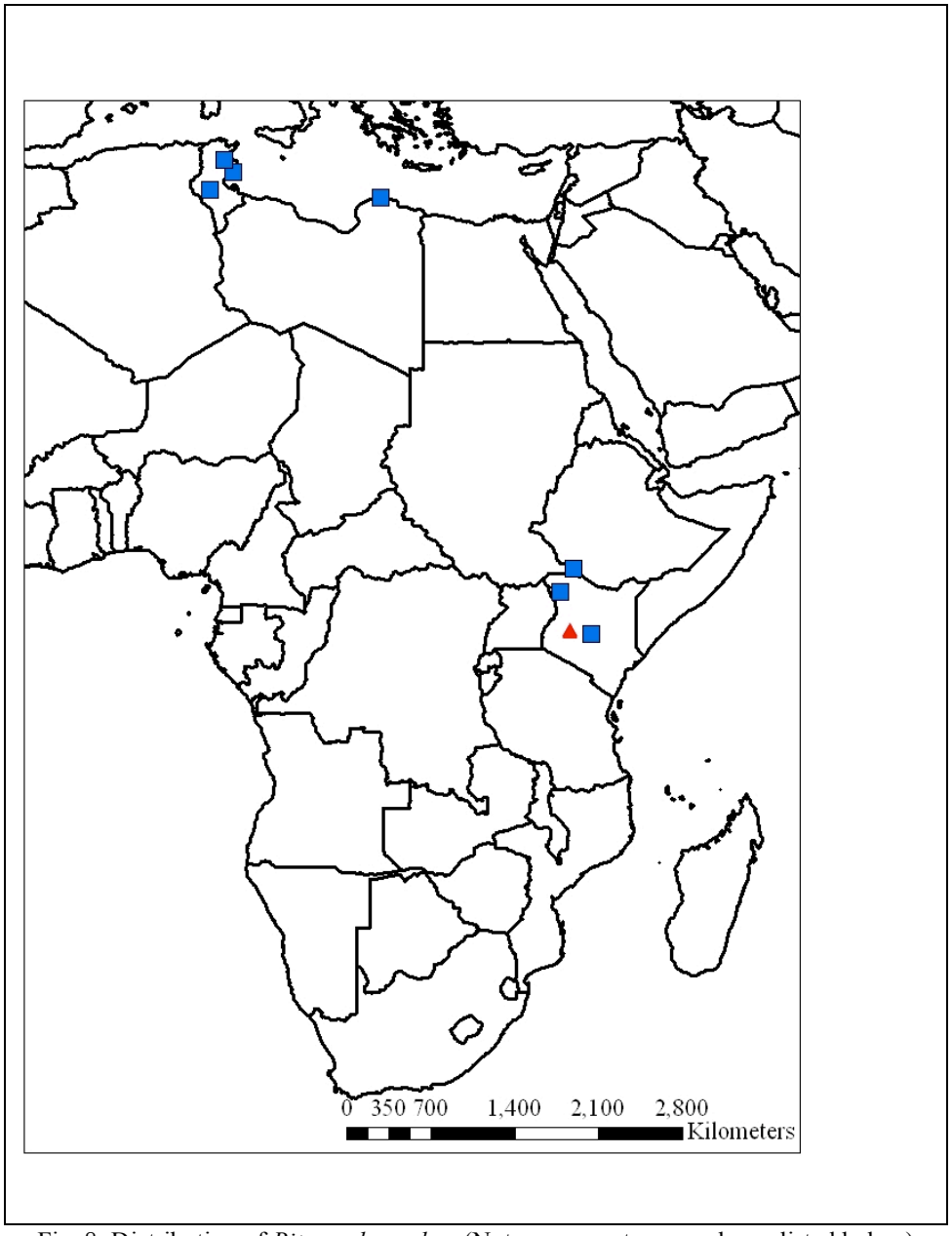

Fig. 8: Distribution of *Biton velox velox.* (Notes on country records are listed below)

ETHIOPIA: South Omo Province, Bourille/Omo River (Fage & Simon 1936; Roewer 1941) as *B. dmitrievi.*

ITALY: No specific locality (Harvey 2003).

KENYA: Eastern Province, Meru Area (Fage 1936; Roewer 1941); Lake Bogoria National Reserve, Kalodeke/South Turkana (Fage 1936; Roewer 1941), Loboii Gate, 0.351167N, 36.063167E, 9.VI.06, Reddick and Mugambi, 1 male (NMK), Loboii town (Mobile Charging Shop), 0.355250N, 36.064944E, 12.II.07, Reddick and Mugambi, 1 male (NMK), Lake Bogoria National Reserve, Acacia Campsite, 0.197528N, 36.108139E, 13-14.II.07, Reddick and Mugambi, 2 males (NMK), Behind Loboii Gate at Lake Bogoria National Reserve, 0.350790N, 36.062330E, 14.II.07, Reddick and Mugambi 2 males (NMK), Lake Bogoria National Reserve, 0.217833N, 36.083333E, 26-28.IV.07, Reddick and Mugambi, 1 male, 1 immature female (NMK).

LIBYA: Cyrenaica (Roewer 1934)

TUNISIA: Gabes Province, Qabis; Quibili (Kebili) Province, Dejebel Oum Ali (Simon 1885) (not seen), Sfax (Roewer 1934), Kairouan (Roewer 1934).

Remarks

There seems to be a great deal of confusion between records for *B. velox dmitrievi* and *B. velox velox* in Harvey (2003). Many of the country records for *B. velox velox* are based on misidentifications and should be ascribed to *B. velox dmitrievi*. Country records above from Fage (1936) should be placed under *B. velox dmitrievi*, since *B. dmitrievi* was synonomized under *B. velox* (but retained as a separate

subspecies) by Delle Cave & Simonetta (1971). Fage's specimens need to be compared side-by-side with typical *velox* to clear up the confusion. For now, the distribution stands. Although this subspecies seems to have a wide distribution, in the future it is possible that *B. velox velox* will be shown to have a much smaller range.

Diel Periodicity and Habitat Preference

The *Biton velox velox* found during this survey were all nocturnal in nature; either collected from under rocks during the day, or actively running toward lights at night. Their darker, muted colors allow them to run almost unseen along the sides of buildings, and *Biton* has been categorized as nocturnal by previous workers (Lawrence 1963). The *Biton velox velox* found during this study were collected from various locations in and around Lake Bogoria National Reserve. Most were found under rocks in shallow depressions. There was no obvious specificity as to which kinds of rocks. The specimens that were collected from Acacia Campsite were found under rocks very near the alkaline lakeshore.

Daesiidae

The distribution of *Hemiblossia brunnea* Lawrence, 1953 is shown in Figure 9.

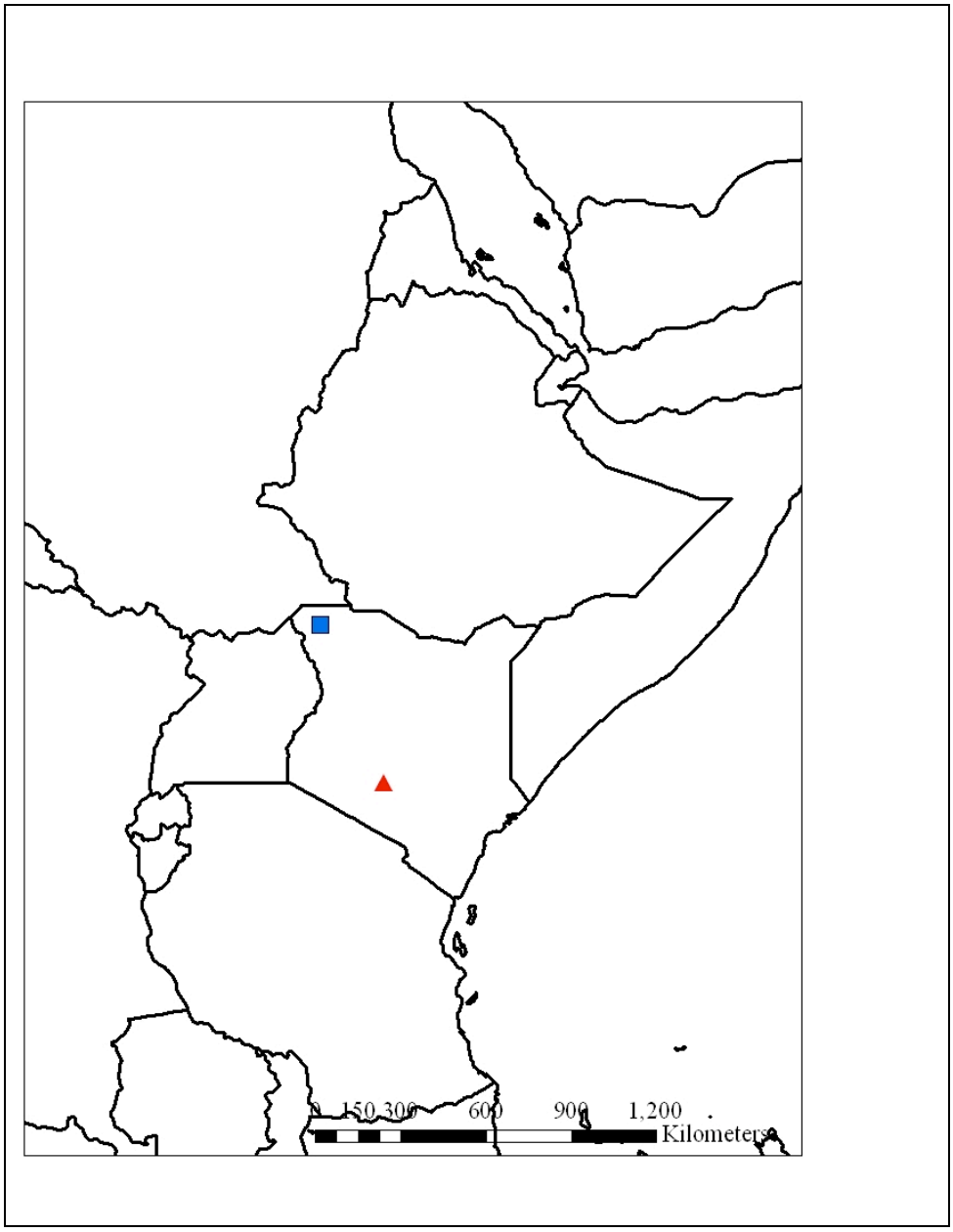

Fig. 9: Distribution of *Hemiblossia brunnea.* (Notes on country records below.)

KENYA: Nairobi Province, Ngong/Matasia, 13.V.07, Mugambi, 1.353338S, 36.656570E, 1 male (NMK); Rift Valley Province, northern Turkana, II-VI.1952, 1 male, 1 female (Lawrence 1953).

Remarks

The specimen collected in the Nairobi city limits matches very closely with *H. brunnea* on the basis of the flagellum and the bristles of the pedipalp metatarsus and tarsus, but there are certain discrepancies. Lawrence (1953) describes *H. brunnea* as having 8-10 reddish brown ctenidia on sternites 3 and 4, however the Ngong/Matasia specimen is lacking those features. Also, Lawrence's descriptions and subsequent keys to species of *Hemiblossia* (Lawrence, 1968) are based largely on color patterns of the body and legs. For *H. brunnea* however, there is no description of color (or the absence of color) on the legs. If the Ngong/Matasia specimen is not *H. brunnea*, it most certainly belongs in the *bouvieri* group, to which *H. brunnea* belongs, because of the pedipalp bristles and the broad, flat flagellum.

Diel Periodicity and Habitat Preference

This specimen from Ngong was collected at dusk, around 6:00 pm, running toward a light in a house yard. Habitat of the only specimen previously collected (the holtype) was not noted in the original description.

Daesiidae

The distribution for *Hemiblossia sp. (undetermined)* is shown in Figure 10.

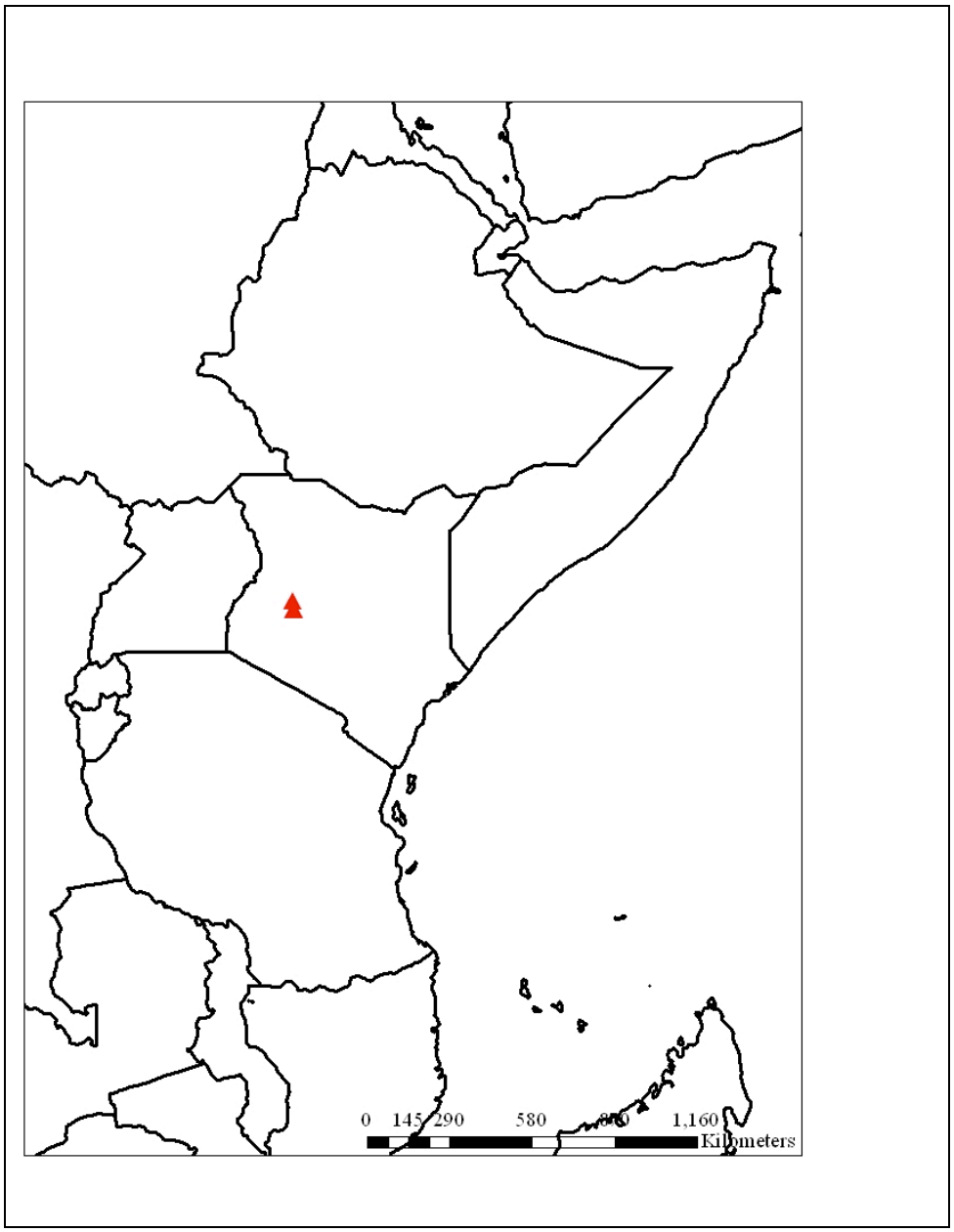

Fig. 10: Distribution of *Hemiblossia sp.* (undetermined).

KENYA: Rift Valley Province, Loboii Town/Lake Bogoria National Reserve at Loboii Gate, 0.353110N/ 36.064620E, 12-14.II.07-28-30.IV.07, Reddick and Mugambi, 2 females, 2 immatures, Lake Baringo National Reserve, 0.632220N/ 36.032570E, 29.IV.07, Reddick and Mugambi, 2 immatures (NMK).

Remarks

The *Hemiblossia* collected at Lake Bogoria do not fit either of the described species from Kenya, *H. bouvieri* or *H. brunnea*, using Roewer's (1933) key and Lawrence's (1953, 1968) keys with color patterns. Without a male in this collection, it is nearly impossible to determine if they are in fact a recognized species recorded from another country. The females and immatures in this collection each have the same coloring: base color of animal pale whitish-yellow with a band of dark brown around distal ends of femur and tibia of pedipalp. The entire metatarsus and tarsus of pedipalp are dark brown. The sides of the arcus posterior are dark with the median area pale, sometimes with very light brown at the very center. Sides of the opisthosoma are dark brown, with dark brown tergites, but pale yellow-white in between each tergite of the opisthosoma. Legs are pale yellow but all legs entirely ringed at distal end of femur with band of light to dark brown. Distal-lateral sides of tibia of legs I-IV are also light brown. The headplate and chelicerae are dark brown, but tips of chelicerae are reddish. The entire ventral side of the solifuge is pale yellow.

Diel Periodicity and Habitat Preference

Four of the above specimens were collected running in the middle of the day. *Hemiblossia* are not brightly colored, as diurnal solifuges are predicted to be, by the precedent set by large, brightly colored species like *Metasolpuga picta*. *Hemiblossia* are, however, piebald with striking patterns, and this characteristic, in lieu of bright colors, may provide some camouflage in order to break up their outline when active in the day. This is not the first time *Hemiblossia* have been recorded to exhibit diurnal behavior, as Purcell (1902) noted that *Hemiblossia oneili* could be found running around in the sunshine.

Three of the above specimens were collected in close proximity to human dwellings, one in a shop during the day, one in a bathroom at night, and one on a footpath during the day. Both of the *Hemiblossia* found near Lake Baringo were found under stones, whereas the four remaining specimens collected from Loboii Town and Loboii Gate at the Lake Bogoria National Reserve were found running in the open.

Daesiidae

The distribution of *Tarabulida* Roewer, 1934 is shown in Figure 11.

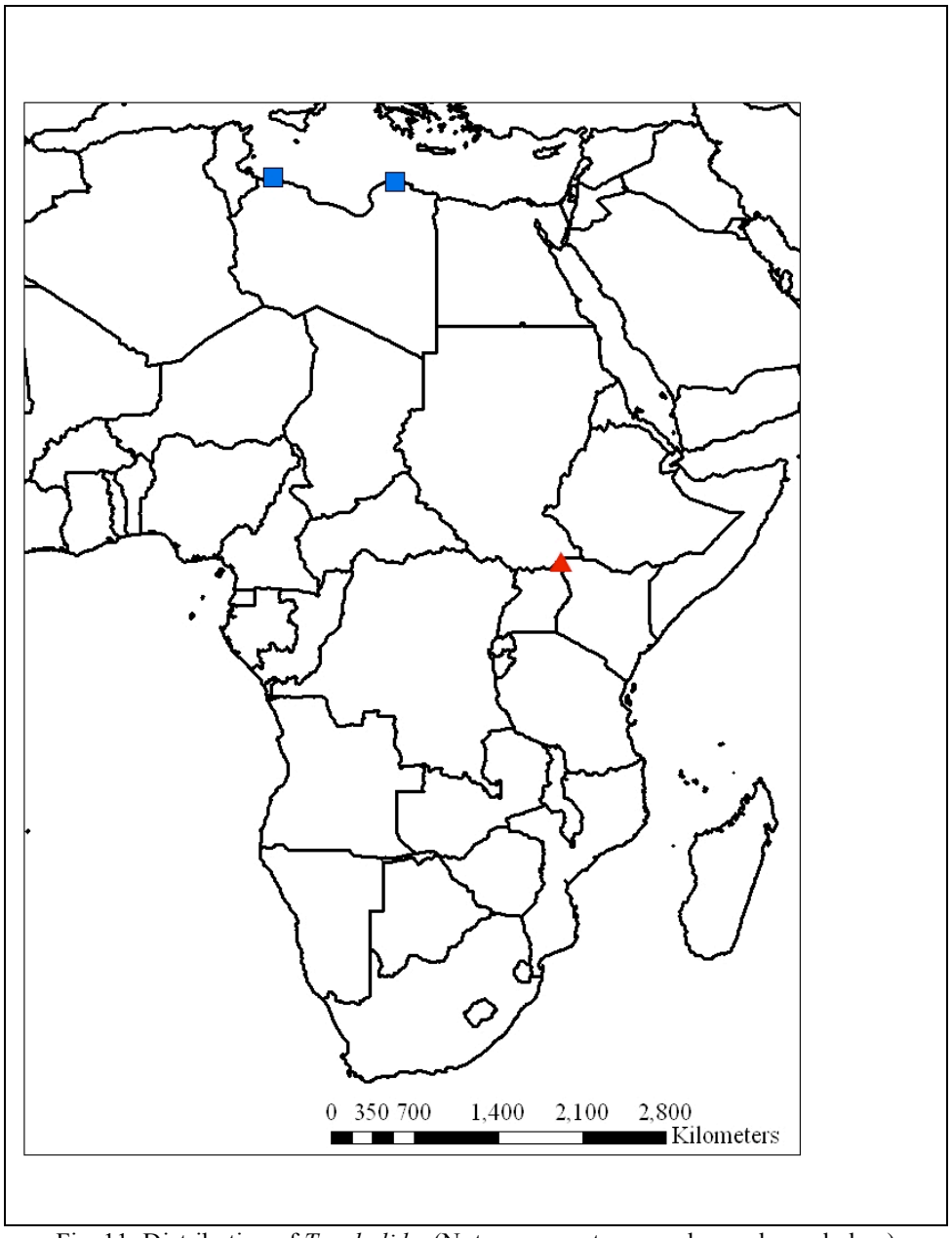

Fig. 11: Distribution of *Tarabulida*. (Notes on country records are shown below)

KENYA: Rift Valley Province, Lokichoggio, base of Mogila Range, 4.210330N/ 34.375510E, 16-18.III.07, Reddick Wharton and Mugambi, 1 male, 2 immatures (NMK), Lokichoggio, northwest of town, 4.213020N/ 34.350620E, 18.III.07, Reddick, Wharton and Mugambi, 1 immature (NMK).

LIBYA: Tripoli Province, Tripoli (formerly Tarabulus) (*T. ephippiata* Roewer 1934); Cyrene (formerly Kyrenaika) (*T. fumigata* Roewer 1934).

Remarks

Roewer (1934) described the genus *Tarabulida* from 2 female specimens collected in Libya. This genus was placed in the subfamily *Gnossipinae* due to the 1-1-1-1 tarsal formula shared by all genera in this subfamily. Each specimen was described as a different species, *T. ephippiata* Roewer and *T. fumigata* Roewer. Males from this genus have not previously been collected or described. A male daesiid and two associated immatures, collected during this study in Lokichoggio, Kenya, on the border of Sudan and Uganda fit the description of *Tarabulida*. Since the genus and its originally included species were not described from males, the species from Kenya could not be determined. However, the chaetotaxy of the tarsi of leg IV exactly matches that of Roewer's description for *Tarabulida*. Since so much of Roewer's classifications rely on chaetotaxy (and indeed this particular arrangement of spines is very different from all others in the subfamily), the male and associated immature specimens clearly belong in this genus.

There are some morphological discrepancies between Roewer's (1934) description and the individuals collected in Lokichoggio, Kenya. First, there is a

question of spination on the pedipalps. The females of both species described by Roewer have smooth pedipalps; whereas the male and both immatures collected in this study have spines on both the tibia and metatarsus of the pedipalp. This may be explained by sexual dimorphism, as there are many cases of males and females having different morphological characters, most notably dentition. However, it could also be that the individuals collected in Kenya are a different species than those from Libya, with species-level differences in pedipalp spination as occurs in *Hemiblossia* (another member of the Gnossipinae).

This discrepancy in pedipalp spination, along with the massive gap in distribution between Libya and Northern Kenya, might argue against the inclusion of our species in *Tarabulida.* However, the chaetotaxy, which is central to Roewer's other generic characterizations, is identical to the type species of Tarabulida and argues against the need to create yet another monotypic genus of Solifugae.

Species Description

Coloration: Legs, head-plate and chelicerae entirely light brown. Anterior margin of head plate outlined with very thin dark brown line extending posteriorly to delineate the exterior lobe of prosoma from the rest of the head-plate. Femur and tibia of pedipalps light brown but slightly darker towards distal end of tibia. Metatarsus and tarsus of pedipalp entirely white. Opisthosoma entirely medium brown (darker than brown of legs) with wide terga the same color. Arcus posterior, meso- and metapeltidium light brown with integument between the same color as legs.

Flagellum: membranous, broad, laminate, incurled at the base, but not tubular as in *B. tigrinus*. Once incurled, the ventral and dorsal sections of the funnel have projections that look strikingly like the cilia on the leaves of a Venus Fly-Trap plant. The distal end of the flagellum is very thin and hair-like with no projections.

Dentition: Moveable finger with two large triangular teeth with one small intermediate tooth, which is situated closer to the proximal large tooth than the distal one. Four cheek teeth of approximately the same size on the immoveable finger. The outer series comprised of three large teeth. The two distal triangular teeth thin, and extremely slanted toward the end of the chelicerae. The proximal tooth, large and triangular, with a very small triangular dorsal notch, that almost looks like an extra small tooth.

Spination: Chelicerae with many thick spines, ranging in size from very small to long, the longer spines forming a line dorso-medially along the chelicerae. Head-plate also covered in spines of varying length, most notably, lined with spines along the posterior edge of headplate, some pointing anteriorly, some posteriorly, giving the appearance of a collar. Ventral surface of both femur and tibia of pedipalp lined with long spines. Metatarsus of pedipalp with six pairs of shorter spines of equal length, evenly spaced.

Ctenidia: Sternite II with a group of six to seven long, pointed ctenidia on each side of midline, golden brown in color.

Dimensions: Total body length incl. chelicerae-- 17mm. Length of chelicerae-- 4mm. Length of leg IV-- 22 mm. Length of pedipalp-- 15.5 mm.

Note: There is a slight suture, more pronounced on some specimens than others, on the tarsi of the fourth leg. However, it is not articulated and therefore the tarsi consists of a single segment.

Diel Periodicity and Habitat Preferences

The Tarabulida specimens were collected from under rocks during the day, which indicates nocturnal activity. The habitat was extremely hot and dry, but subject to flooding from the near-by river and solifuges were found in shallow depressions under rocks along the base of large hill. The hills and river-bed were sparsely populated with small bushes and various xeric plants.

Galeodidae

The distribution of *Galeodes arabs arabs* Koch, 1842 in Kenya is shown in Figure 12.

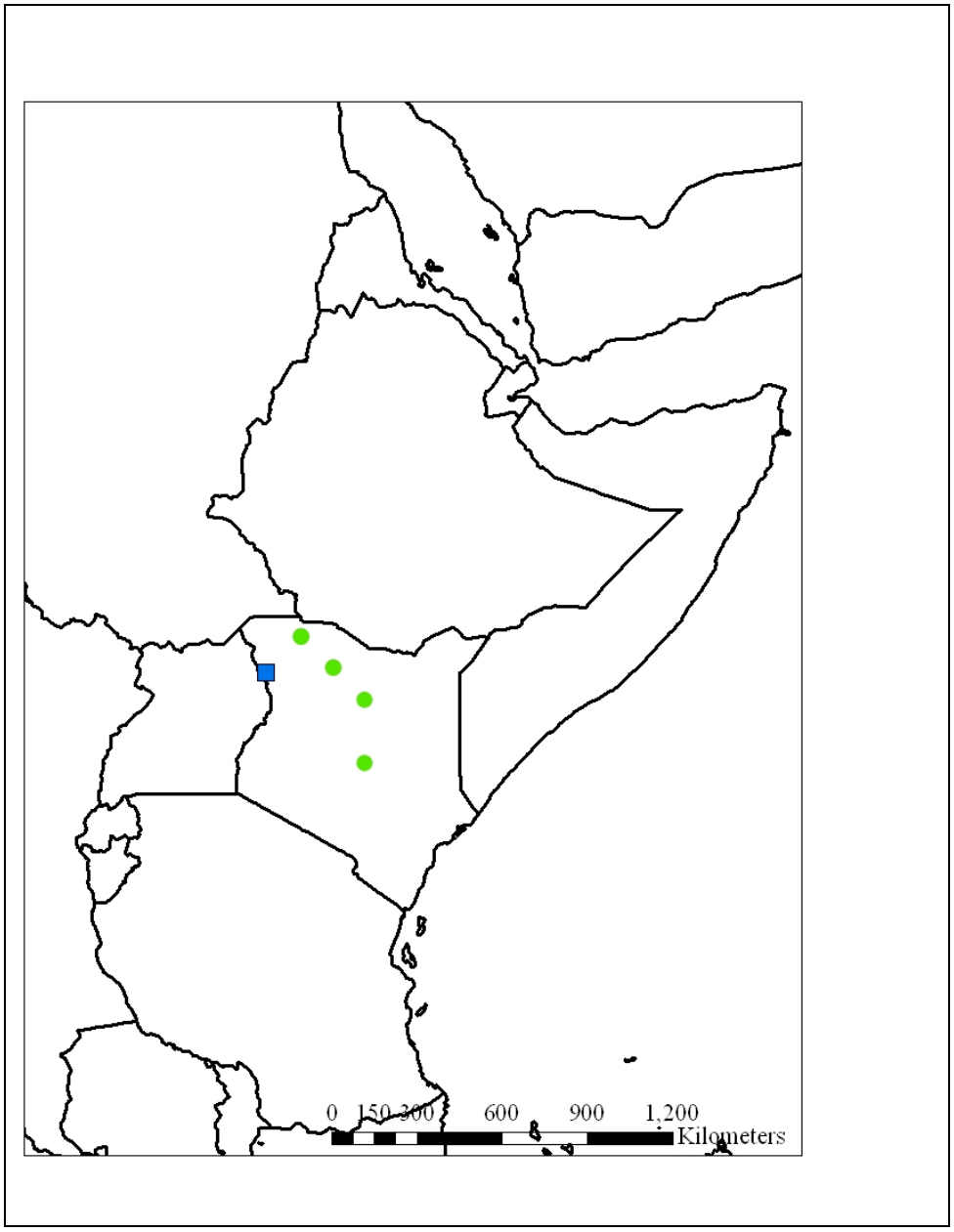

Fig. 12: Distribution of *Galeodes arabs arabs* in Kenya. (Notes on country records are listed below)

KENYA: Rift Valley Province, Lake Turkana W. Von Hohnel Bay, 12. IX.1980, 1 male (NMK), L. Turkana Alia Bay Rocodonia Camp, 8.VIII.1980, 1 male, 1 immature (NMK), Camp at Alia Bay, IX.1980, 1 immature male (NMK), Loyongalaui Lake Rudolf, I.1962, 1 male, (NMK), Sibiloi National Park (Alia Bay), 29.XII.2004, 1 male (NMK), Ileret Ethiopia Border near L. Turkana, V-VII.1996, 1 immature male, (NMK), Shaba National Reserve, nr. Buffalo Springs Reserve, 1 female (NMK); Eastern Province, Marsabit K.C., VI.1951, 1 male (NMK), Nr. Koobi Algi, 31.VIII.1980, 1 male (NMK), Qarsa-Galas Area, 8.VII.1980, 1 immature female (NMK), Muru Hill (Roewer 1941).

Remarks

This species is one of the most widely distributed solifuges, being recorded from northern Kenya up through Djibouti, Saudi Arabia, Syria, Iran, Iraq and Israel and west to Algeria and Morocco (Harvey 2003). Roewer (1941) lists *Galeodes arabs* distribution as far south as Turkana in Kenya in the Muruduris Mountains. The closest modern day approximation to this locality would be Muru Hill, west of Lake Turkana, part of the western ridge of the Rift Valley. Therefore, this study provides the southernmost distribution record for *Galeodes arabs* in Shaba National Reserve, at the southern end near Buffalo Springs National Reserve, and the southern most distribution records for the family Galeodidae.

There has been a great deal of confusion between *G. arabs* and *G. granti* Pocock, 1903 as well as several other misidentifications in the literature. Cloudsley-Thompson (1961a/b) published detailed studies on the natural history, physiology, and behavior of

G. arabs, however the species was later identified as *G. granti*. Other species have been misidentified as *G. arabs*, like *G. araneoides* Pallas, 1772 and subsequent synonomies of several different species further serve to confuse information about *G. arabs*. The correct application of the name for the species occurring in Kenya will require a detailed revision of the African Galeodidae.

Diel Periodicity and Habitat Preference

Pocock (1897) recorded *Galeodes arabs* as being a nocturnal species, feeding on beetles at night, as relayed to him by the collector. The coloration is typical of other nocturnal species, large and pale with no defining markings (Lawrence 1963). Since the specimens in this study were all from the NMK holdings, and no specific habitat information was included with their locality labels, there is no information on habitat preference. For additional information on *Galeodes*, see the works by Cloudsley-Thompson noted above.

Rhagodidae

Remarks

East African rhagodids are extremely difficult to identify, as the only real key is provided by Roewer (1934), and many of the species found in Kenya are also described in the same publication. Generic descriptions rely primarily on spination of the tarsi, which is often variable and difficult to determine. Often, rhagodid species are described chiefly on color patterns, particularly the color of terga on the opisthosoma. The unidentified rhagodids treated below do not fit *Rhagodoca*, the only genus previously

reported from Kenya and do not fit original descriptions of any of the species previously recorded from Kenya.

No information is available on diel periodicity or habitat usage of rhagodids. Rhagodids may be a larger counterpart to Hexisopodidae in the south, with respect to their ecology and biology. They have the largest chelicerae relative to body size of any of the Solifugae and have relatively short, stout, spiny legs. Eco-morphologically, this could point to a psammophilous existence, or at the very least, a tendency to dig very deep burrows, which might explain the complete lack of habitat or specific locality information on these animals.

The distribution of *Rhagodoca bettoni* Roewer, 1933 is shown in Figure 13.

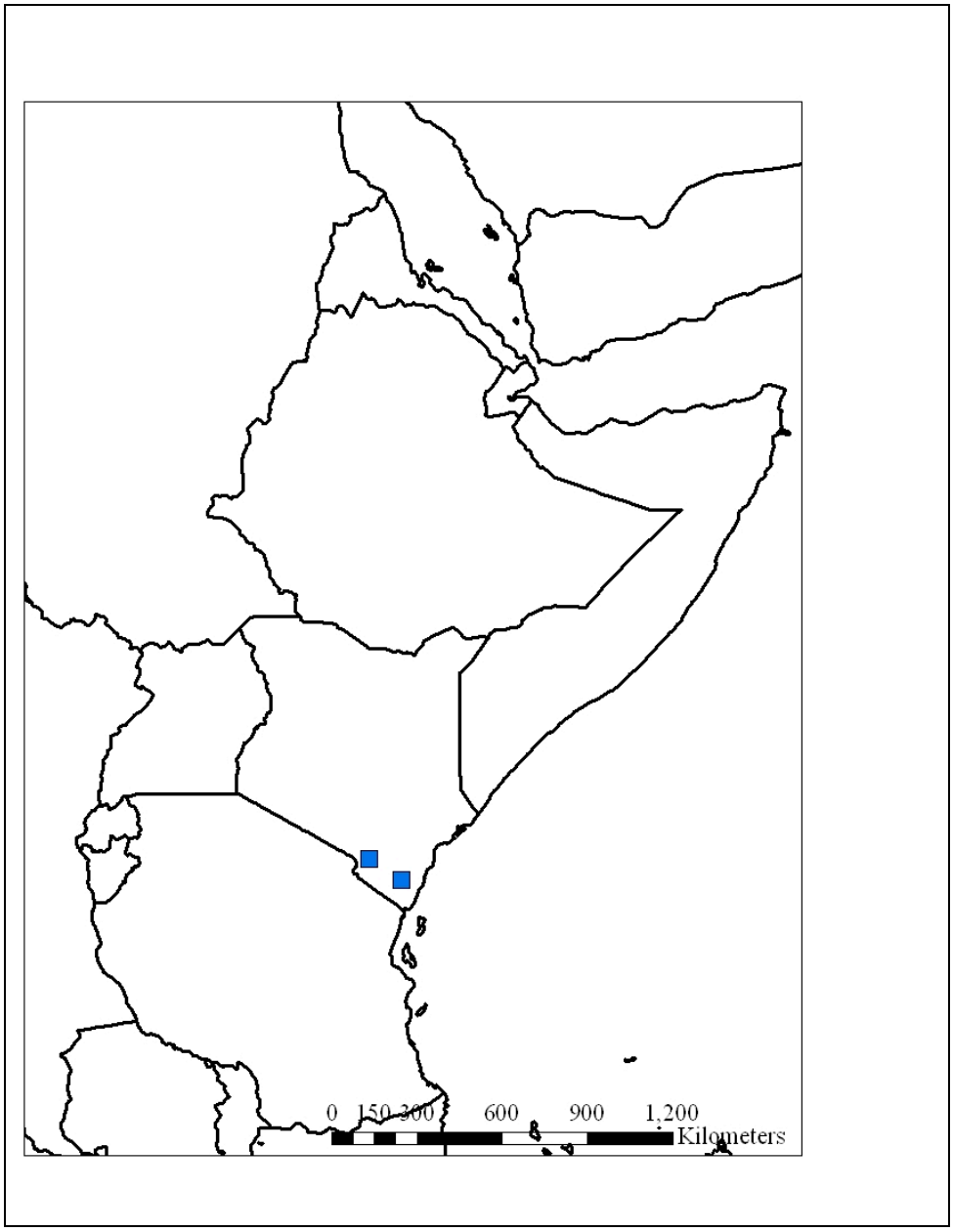

Fig. 13: Distribution of *Rhagodoca bettoni*. (Notes on country records are listed below)

KENYA: Coast Province, Maungu Rukinga Ranch, Voi, IV.1984, 1 female, 1 immature (NMK), Voi, Rukinga Ranch, 1 male (NMK); Tsavo River (Roewer 1934); Rift Valley Province, Samburu, Jaru Desert (Roewer 1934).

Diel Periodicity and Habitat Preference

These specimens were found in the holdings of NMK with no associated information about activity patterns or habitat.

Rhagodidae

The distribution of *Unidentified Rhagodid #1* is shown in Figure 14.

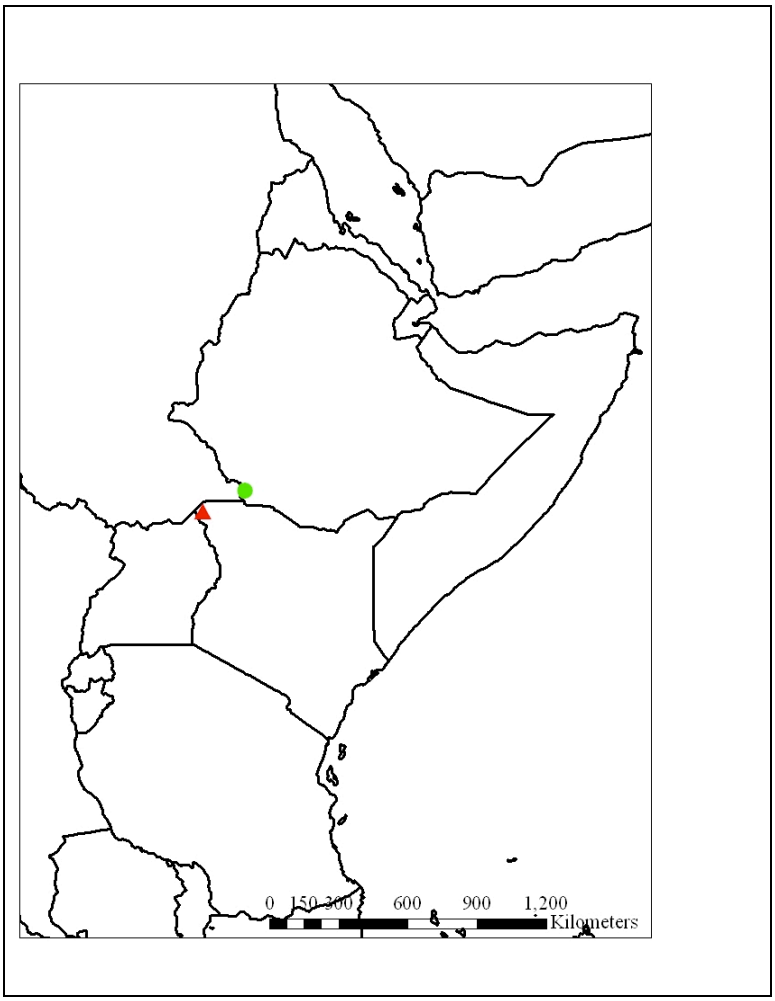

Fig. 14: Distribution of Unidentified Rhagodid #1. (Notes on country records are listed below)

ETHIOPIA: Omo River, VIII.1969, 1 male (NMK).

KENYA: Rift Valley Province, Lokichoggio, near river bed, 4.211460N, 34.348790E, 17.III.07 Reddick, Wharton and Mugambi, 1 male (NMK).

Rhagodidae

The distribution of *Unidentified Rhagodid #2* is shown in Figure 15.

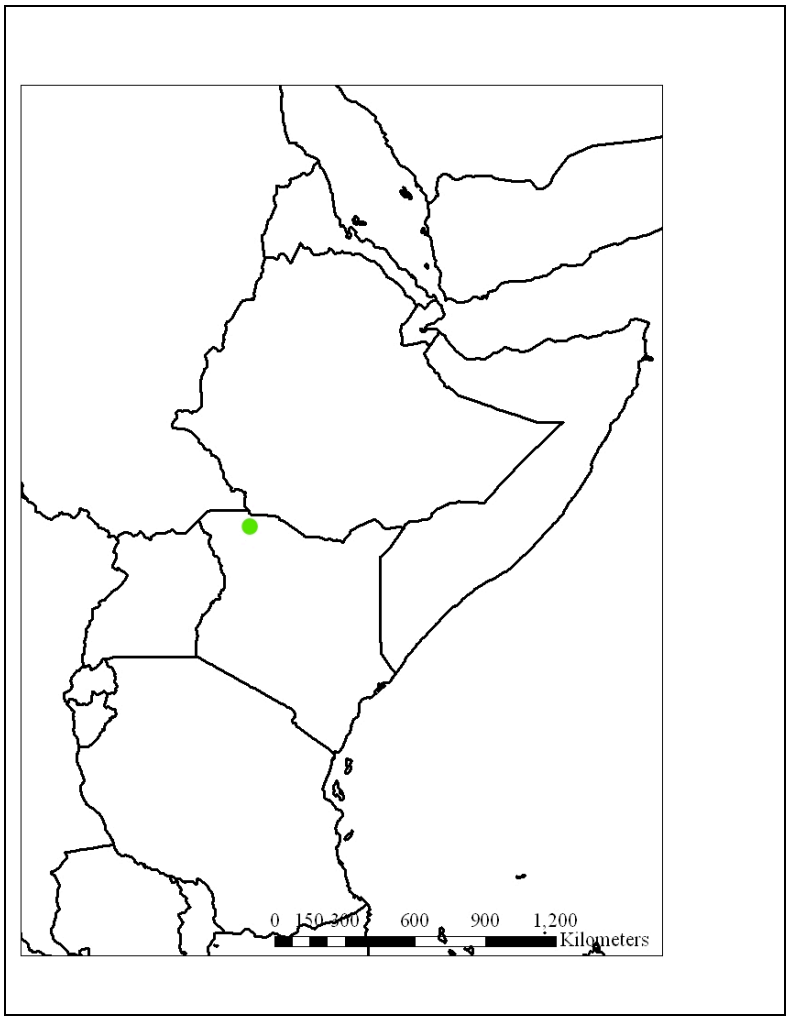

Fig. 15: Distribution of Unidentified Rhagodid #2. (Notes on country records are listed below)

KENYA: Rift Valley Province, Turkana, Rocodoni Camp, Alia Bay, 3.IX.1980, 1 male (NMK).

Rhagodidae

The distributions for *Unidentified Rhagodids #3, #4 and #5* are shown in Figure 16.

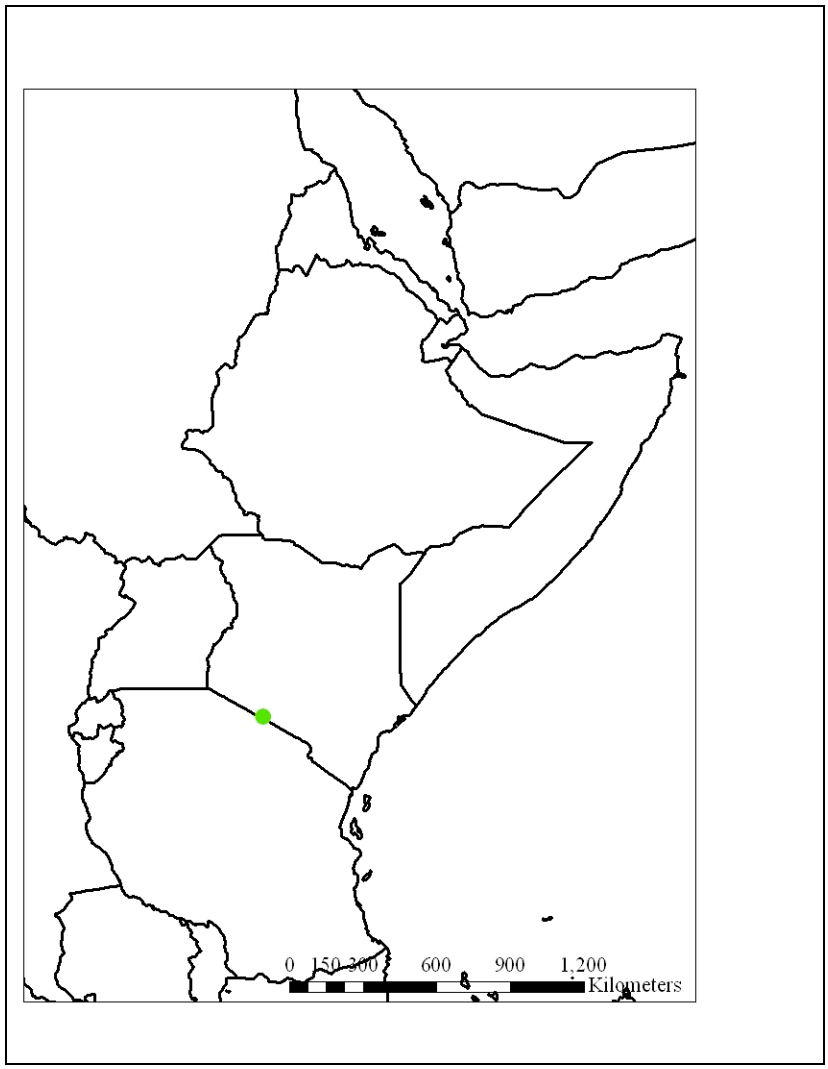

Fig. 16: Distribution of Unidentified Rhagodids #3, 4, and 5. (Notes on country records are listed below)

KENYA *(unidentified rhagodid #3)*: Rift Valley Province, Olorgesailie, -1.633333S, 36.435000E, 10.VI.1978, 2 males (NMK).

KENYA *(unidentified rhagodid #4)*: Rift Valley Province, Nguruman, Nguruman Campsite, 1.III.1985, 1 male (NMK).

KENYA *(unidentified rhagodid #5)*: Rift Valley Province, Olorgesailie, II.2007, John Barthelme, 3 males (NMK).

Solpugidae

The distribution of *Solpugyla* Roewer, 1933 (*undetermined species)* is listed below.

KENYA: Eastern and Coast Province, Tsavo West National Park, Mtito Andei Gate, 2.696167S/ 38.165333E, 29.V.2006, Reddick and Mugambi, 1 immature female (NMK).

Remarks

The genus *Solpugyla* was described by Roewer in 1933 using the type species *Solpuga darlingi* Pocock, 1897. Identification of *Solpugyla* is difficult due to the intraspecific variation in chaetotaxy of tarsi of the fourth leg, used by Roewer in his generic keys. *Solpugyla* is very similar to *Solpugiba* Roewer, 1934 in terms of chaetotaxy, but *Solpugiba* has two small intermediate teeth between the anterior teeth of

the dorsal jaw, whereas *Solpugyla* has none (Roewer 1933, 1934; Lawrence 1963). The specimen found in Kenya is an immature female, and it is possible that the smaller, intermediate teeth are present only in more mature individuals. It would therefore be useful to have additional specimens, preferably adult males, for verification.

Although this is the first record for *Solpugyla* from Kenya, it is not unexpected. This genus has been described from southern Africa north to the Democratic Republic of the Congo, Tanzania, Ethiopia and Somalia but has not been collected before now from Kenya. This record serves to reinforce and fill-in the distribution of *Solpugyla* through East Africa.

Solpugidae

The distribution of *Zeria fordi* (Hirst, 1907) is shown in Figure 17.

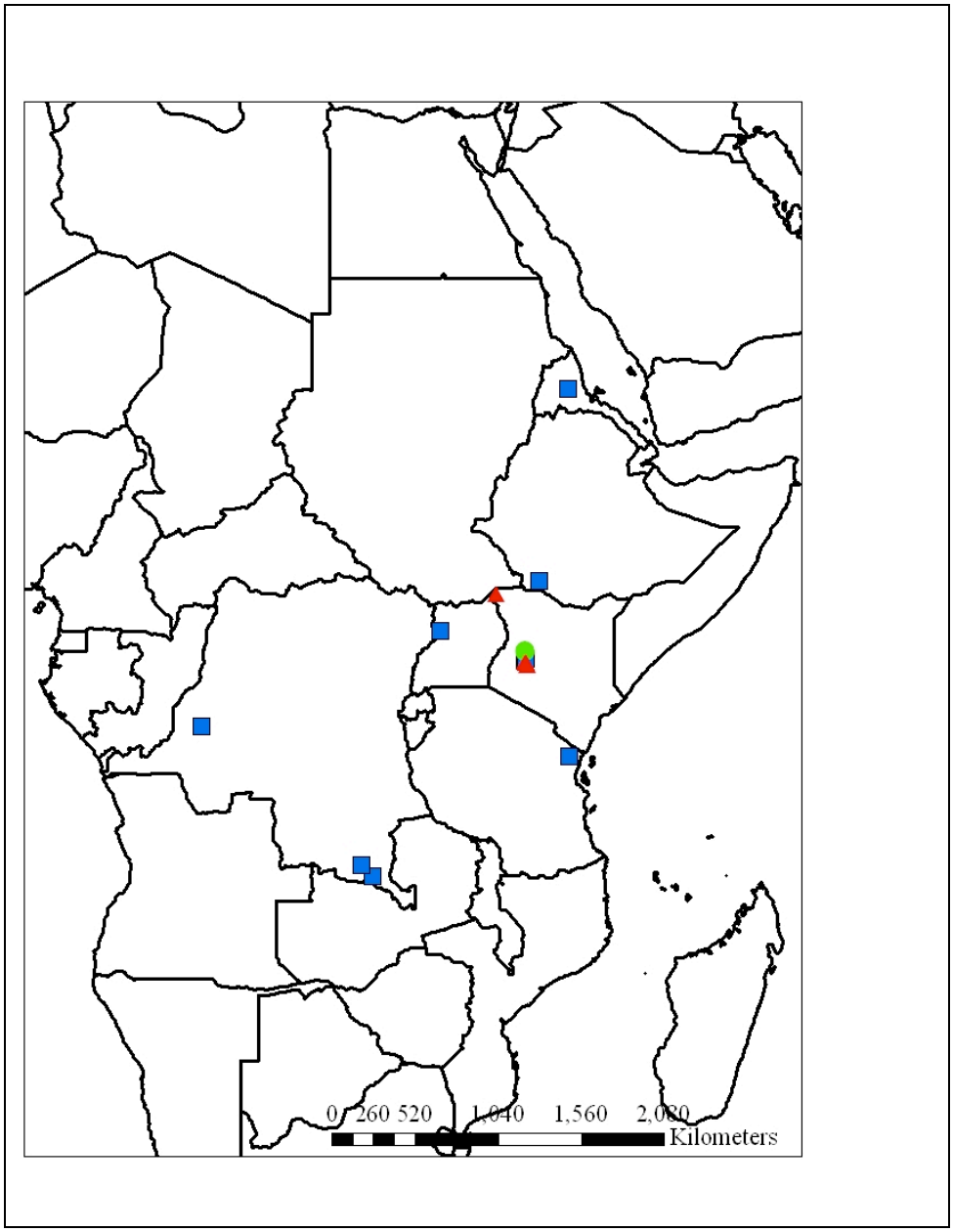

Fig. 17: Distribution of *Zeria fordi*. (Notes on country records are listed below)

DEMOCRATIC REPUBLIC OF CONGO: Ituri Province, Mahagi Port and Ishwa (Roewer, 1941); Katanga Province, Elisabethville and Jadotville (Benoit 1960).

ERITREA: Anseba Province, Keren (Formerly Cheren) (Zavatarri 1930(not seen); Simonetta & Delle Cave 1968).

ETHIOPIA: Sagan-Omo District, Gondaraba, Omo Valley (Caporiacco 1941; Delle Cave 1971).

KENYA: Rift Valley Province, Marigat (Roewer 1933), Eastern Shore of Lake Turkana, IV-V.1982, Coll. unknown, 1 male (NMK), Shore of Lake Turkana (as Rudolf) (Roewer 1933), Lake Baringo (Hirst 1907), Lake Baringo, 25.XII.1984, Coll. unknown, 1 male (NMK), Lake Bogoria National Reserve, 0.217500N, 36.098500E, 7.VI.06, Reddick and Mugambi, 1 female (NMK), Lake Bogoria National Reserve, 0.351611N/36.063528E, 11-17.II.2007, Reddick and Mugambi, 3 males, 2 females, 2 immatures (NMK), Lokichoggio, 4.213400N/34.348930E, 15.III.2007, Reddick, Wharton and Mugambi, 1 male (NMK), Lake Bogoria National Reserve, 0.351611N/36.063528E, 26.IV-1.V.2007, Reddick and Mugambi, 2 males, 3 immatures (NMK).

TANZANIA: Tanga Region, Usambara Mountains (Roewer 1934).

SUDAN: Kordofan Province, Nuba Mountains, Talodi (Roewer 1934).

UGANDA: Aios (Hirst 1912; Roewer 1934).

Remarks

Mature males were readily identified as *Z. fordi* due to the distinct flagellum and the mature females fit the coloration pattern defined by Hirst (1912) with dark brown tergites bordered by grey integument. Hirst (1907) described the type of this species from the Lake Baringo area of Kenya, in the Northern Rift Valley and all specimens from this study were all collected from the Rift Valley of Kenya. The male found in Lokichoggio, and a male from the NMK collection from the eastern shore of Lake Turkana in north western Kenya help to fill in a gap in distribution between Uganda, southern Sudan and Ethiopia. Harvey (2003) overlooked one record for a mature male by Simonetta & Delle Cave (1968) from Keren, Eritrea, which extends the northern range of this species significantly from south-western Ethiopia. In the same publication, Simonetta & Delle Cave (1968) listed Somalia as a locality for a male specimen from Zavattari's collections. However, the locality is listed as A.O.I, or Africa Orientale Italiano, which consisted of Eritrea, Ethiopia and Somalia.

Diel Periodicity and Habitat Preference

Zeria fordi fits the coloration for a nocturnal species and all specimens were found concealed beneath rocks or bark during the day. All mature males of the species were found in February of 2007 and again on a later collecting trip in late April of 2007. Mature females and immatures were found during the aforementioned months and in June of 2006.

During this survey, *Z. fordi* males and females were found in shallow burrows under rocks at the base of rocky hillsides near Lake Bogoria in the central Rift Valley

with one exception. One mature male from Lake Bogoria National Reserve was found under dead bark of an *Acacia sp.* approximately 0.5m above the ground. The area was overgrown with high grasses from an unusual rainy period in the dry season, which may account for this above-ground finding. In Lokichoggio, a mature male was found in the muddy banks of a wash.

Solpugidae

The country records for *Zeria lobatula* (Roewer, 1933) are listed below.

KENYA: Unknown locality, 1 male (NMK)

TANZANIA: Usambara Mountains (Roewer 1933)

Remarks

This specimen was readily identifiable by its distinctive flagellum. Even though the specimen from NMK has no locality data, it is safe to assume that it does in fact come from Kenya, as there was only one (of the 234 solifuge specimens in the NMK holdings) from another country. The sole exception was a specimen from Ethiopia, right across the border from Kenya.

Diel Periodicity and Habitat Preference

The Usambara Mountains listed as the holotype's locality is too large an area to pinpoint habitat preference. Since the Kenya specimen comes with no locality data from the NMK holdings, there is no further information on activity patterns and habitat preferences of this species.

Solpugidae

The distribution for *Zeria loveridgei* (Hewitt, 1925) is shown in Figure 18.

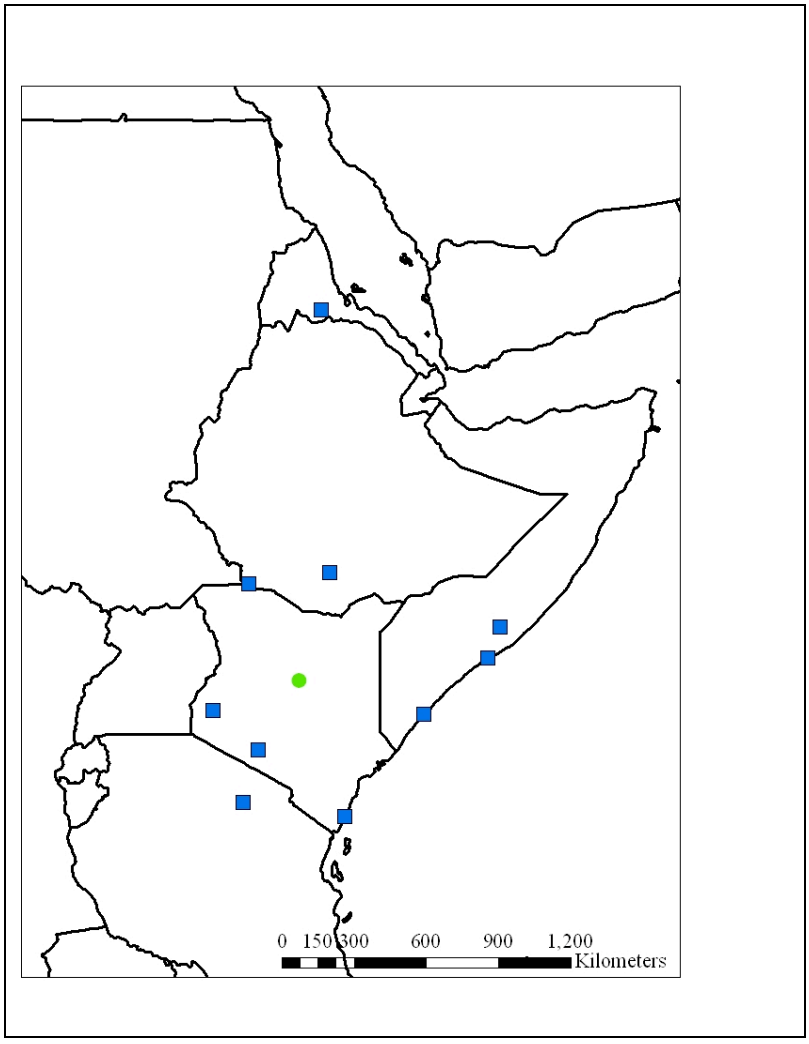

Fig. 18: Distribution of *Zeria loveridgei*. (Notes on country records are listed below)

ERITREA: Adri Ugri (Simonetta & Delle Cave 1968).

ETHIOPIA: Sidamo Province, Neghelli (Caporiacco 1941; Moriggi, 1941; Simonetta & Delle Cave 1968) and Omo Valley (Delle Cave 1971).

KENYA: Coast Province, Mombasa (Roewer 1934); Nyanza Province, Kisumu (Hewitt 1925); Rift Valley Province, Samburu (Buffalo Springs), 22.IV.1978, Coll. unknown, 1 male (NMK), Olorgesailie (Caporiacco, 1949).

SOMALIA: Giumbo (Caporiacco 1941; Moriggi 1941); Duca degli Abruzzi and Dunane (Simonetta & Delle Cave 1968).

TANZANIA: Arusha area, Manjara (Roewer 1934).

UGANDA: no specific locality (Roewer 1934; Moriggi 1941).

Remarks

The male from the NMK collection was readily identified by the distinctive flagellum. The record from Eritrea recorded by Simonetta & Delle Cave (1968) was overlooked by Harvey (2003).

Diel Periodicity and Habitat Preference

Since this specimen was found in the holdings of NMK, specifics about the habitat or diel activity patterns are unavailable.

Solpugidae

The distribution of *Zeria meruensis* (Tullgren, 1907) is shown in Figure 19

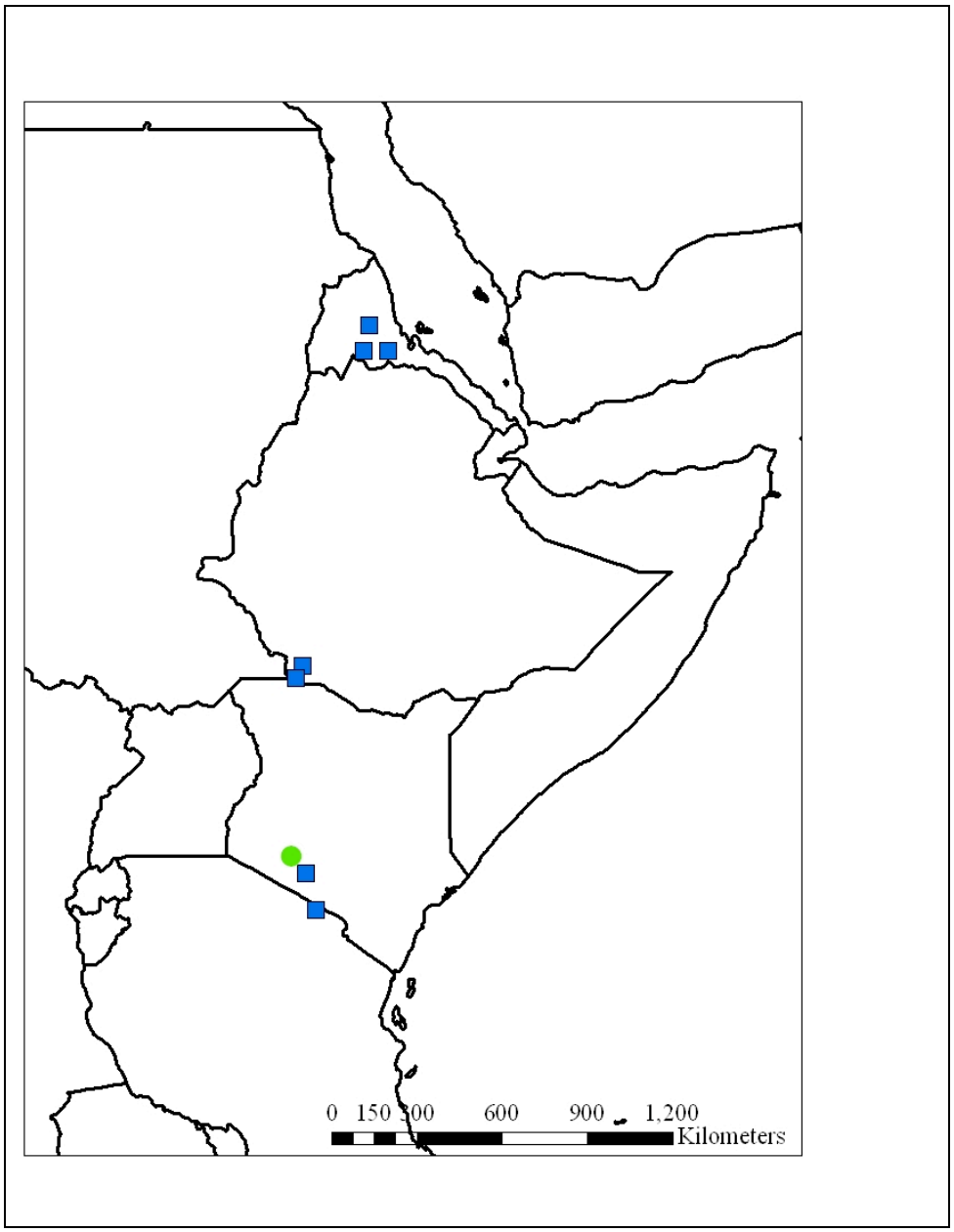

Fig. 19: Distribution of *Zeria meruensis*. (Notes on country records are listed below)

ERITREA: Mai Mefales, Cheren and Mai Edaga (Simonetta & Delle Cave 1968).

ETHIOPIA: Sidamo Province, Bourille and Pianuro de l'Omo (Fage & Simon 1936; Moriggi 1941).

KENYA: Rift Valley Province, Olorgesailie (Caporiacco 1949), Mt. Suswa (no date available, 1 male (NMK).

TANZANIA: Mt. Meru area, lowlands (Tullgren 1907).

Remarks

Harvey (2003) did not recognize that Caporiacco (1949) collected one specimen of *Z. meruensis* from southern Kenya. In addition to this record, that fills the gap in distribution from Tanzania to Ethiopia, another mature male from the NMK holdings found from the Rift Valley in Kenya, supports the widespread distribution of this species.

Diel Periodicity and Habitat Preference

Since this specimen was found in the holdings of NMK, no specifics about the habitat or diel activity patterns can be discussed.

Solpugidae

The distribution of *Zeria nasuta* (Karsch, 1880) is shown in Figure 20.

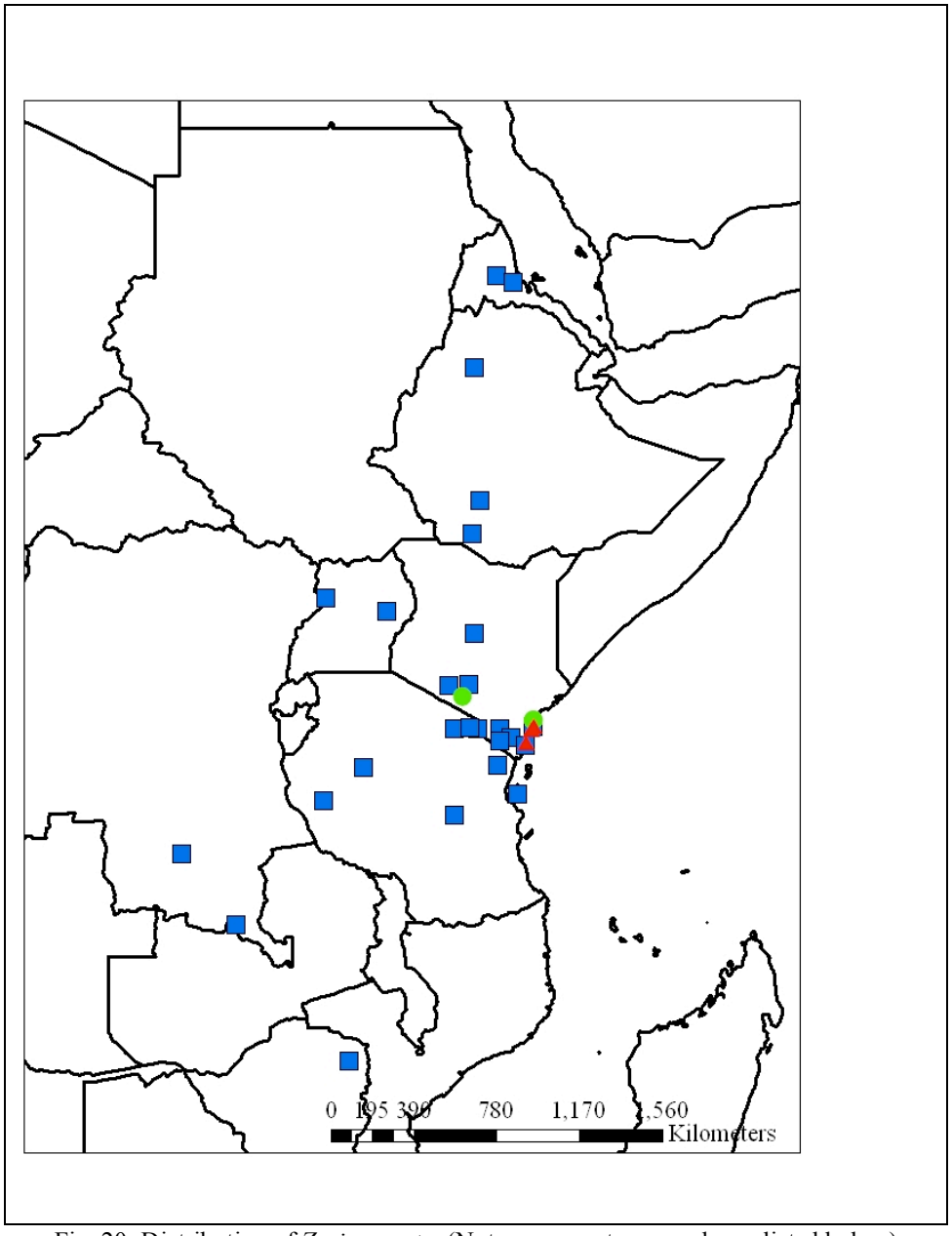

Fig. 20: Distribution of *Zeria nasuta*. (Notes on country records are listed below)

DEMOCRATIC REPUBLIC OF CONGO: Shores of Lake Tanganyika at Mahagi Port (Roewer 1933; Moriggi 1941), Luombva (Roewer 1941), Kakyelo (Benoit 1960), SAnkisia (Benoit 1960), Elizabethsville (Benoit 1960).

ERITREA: Cheren, (Zavatarri 1930 (not seen); Moriggi 1941), Massaua (Roewer 1934; Moriggi 1941).

ETHIOPIA: Amhara Province (Birula 1927; Moriggi 1941); Sidamo Province, El Banno (Caporiacco 1941; Moriggi 1941), Lake Margherita (Kraepelin 1903; Moriggi 1941), Thiba (Roewer 1934).

KENYA: Central Province, Machakos (Roewer 1941); Coast Province, Arabuko Sokoke Forest Reserve, -0.3.41993S, 39.901980E, Reddick Wharton and Mugambi, 2 males, 1 immature male (NMK), Voi (Pocock 1898; Kraepelin 1901; Birula 1926), Mackinnon Rd. (Caporiacco 1949), Taveta (Roewer 1933), Malindi South, 17.V.1981, 1 male (NMK), Galana Ranch nr. Malindi, 21.XI.1977, 1 male (NMK), Mombasa (Roewer, 1933) 20.III.2007, 1 immature (NMK), Gedi Hist. Mon. Kilifi District, 29.XI.1972, 1 male (NMK); Eastern Province, South of Tsavo River (Birula, 1926), Mwea region nr. Upper Thiba River (Birula 1926), Kibwezi (Roewer 1933) Kilwa (Roewer 1933); Rift Valley Province, Samburu (Pocock 1898; Kraepelin 1901), Olorgesailie, 10.VI.1978, II.2007, 2 males (NMK), Kajiado Town, 20.III.1981, 1 male (NMK).

TANZANIA: Arusha area, (Roewer 1933), Zanzibar Island (Karsch 1880), Moshi (Roewer 1941), Usambara Region (Roewer 1933), Maasai-Steppe

(Roewer 1933), Gurui (Roewer 1933), Mpwapwa (Roewer 1933), Tabora (Roewer 1933), Moliro (Roewer 1941; Benoit 1960).

UGANDA: Kapiri (Roewer 1934).

ZIMBABWE: Mtoko (Roewer 1934).

Remarks

This is a very distinctive species, readily identified by the color pattern on the chelicerae and the distinctive flagellum.

Diel Periodicity and Habitat Preference

The two males collected during this survey were found running at night around 9:00pm. It is assumed they were searching for mates. The specimens were found on the edge of the Arabuko-Sokoke Forest on bare, sandy patches near a ranger station and near a busy road. Between the road and the forest, on either side of the ranger station, the habitat was a mixture of tall grass and scattered shrubs.

Solpugidae

The distribution of *Zeria sericea* (Pocock, 1897) is shown in Figure 21.

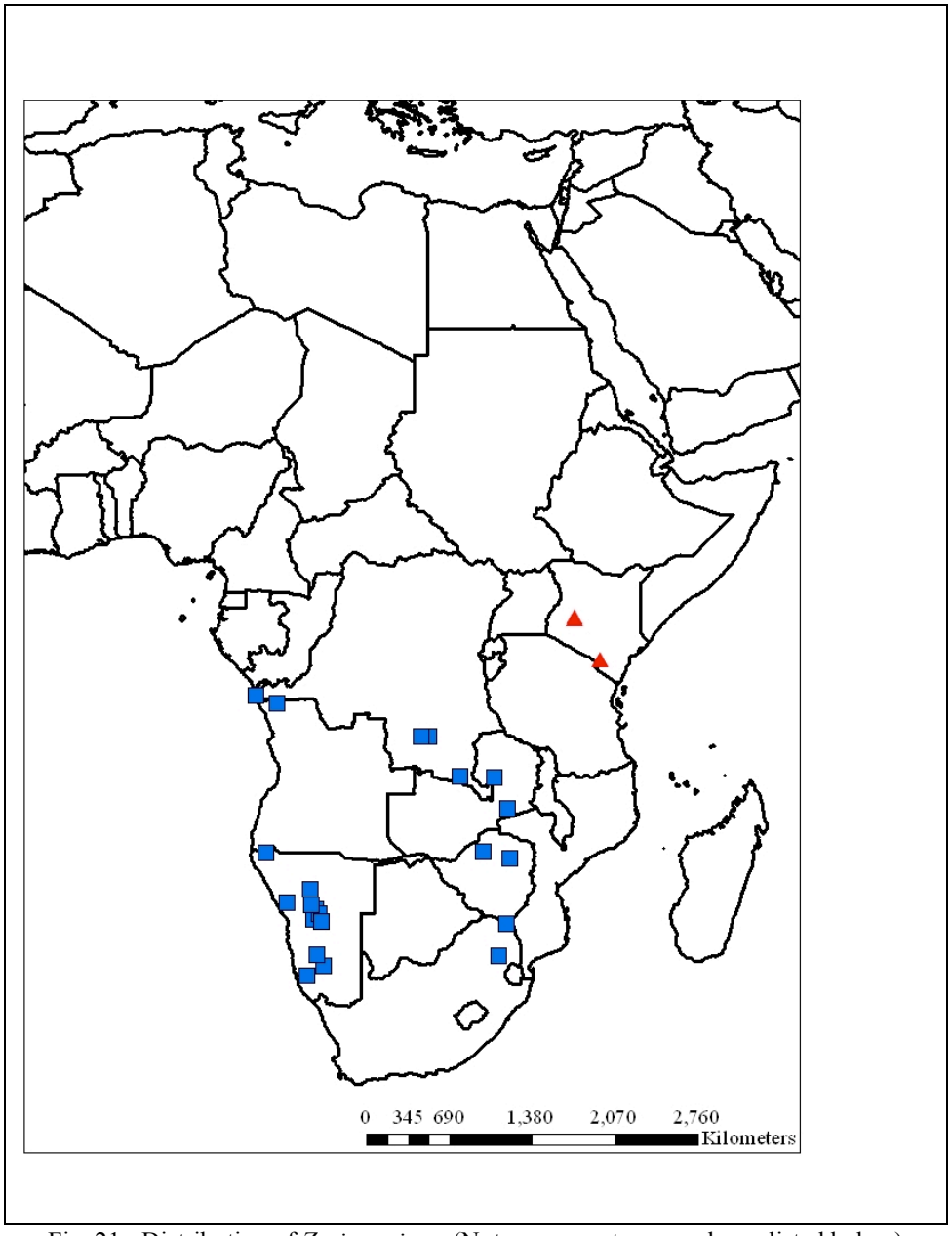

Fig. 21: Distribution of *Zeria sericea*. (Notes on country records are listed below)

ANGOLA: Kakindo and Rio Mbale (Monard 1937 (not seen); Lawrence 1960).

DEMOCRATIC REPUBLIC OF THE CONGO: Elisabethsville, Sankisi (Roewer 1934), Lukonzolura (Roewer 1941).

KENYA: Coast Province, Tsavo West, Shetani Lava Flow, -2.918590S, 38.010780E, 27-28.III.07, Reddick and Mugambi, 3 males (NMK); Rift Valley Province, Lake Bogoria National Reserve, Acacia Campsite, 0.97667N, 36.109000E, 8.VI.06, Reddick and Mugambi, 1 male, 1 immature (NMK), 17-18.II.07, Reddick and Mugambi, 3 males (NMK), , Lake Bogoria National Reserve, Acacia Campsite 27.IV.07, Reddick and Mugambi, 1 male (NMK); No locality listed, 1 female (NMK).

NAMIBIA: Kaokoveld (Roewer 1934), Grootfontein (Lawrence 1929), Sanveld (Roewer 1941), Outjo (Lawrence 1963), Brandberg Mts, Ghaub, Glynberg, Hoba, Naukluft, Okahandja, Otjikoko-Sud, Windhoek (Wharton 1981).

SOUTH AFRICA: Madziringwe, Punda Milia (Lawrence 1964), Sabie Hoek (Lawrence 1967a).

ZIMBABWE: Petauke and Alala Plateau (Hirst 1911), Umfuli, Gadzima (Pocock 1897), Salsbury (Roewer 1934), Mwasha Falls (Lawrence 1953).

Remarks

Pocock (1898), in his original description of *Zeria zebrina*, noted that it was nearly identical to *Z. sericea*; so much so that it did not warrant a full description. *Zeria zebrina* was described from a specimen collected in the Taru desert, an area just north of the Galana River in Kenya's Tsavo East National Park. *Zeria sericea*, though not

previously recorded from Kenya or East Africa, is widespread in areas west and south of the former British East Africa (Harvey 2003), suggesting that our specimens are *Z. zebrina.* There are, however, several morphological characteristics that point to differences between the species (Roewer 1933; Lawrence 1963). Keys provided by Roewer (1934) define important differences in the two species that aided in the determination of our material as *Z. sericea* rather than *Z. zebrina*. First, sketches of the lower dentition of *Z. zebrina* show two small medial teeth between two larger proximal and distal teeth. The specimens collected in Kenya have one large triangular medial tooth. Also, Roewer (1934) states in the key that *Z. zebrina* are without long manes of hair on the legs, while *Z. sericea* has long setae on legs II-IV, with leg IV having even longer, white silky hairs, or a mane (Pocock 1897; Roewer 1934; Lawrence 1963). All specimens collected in Kenya possess these characteristic hairs. Lastly, coloration on the propeltidium can be used to distinguish between the two species. In *Z. zebrina*, the propeltidium is described as darkened or completely dark (Roewer 1934) and the propeltidium of *Z. sericea* is described as having a darkened web or network over a base color of amber. Again, the specimens collected in Kenya fit the description of *Z. sericea.* There are size discrepancies between *Z. sericea* and *Z. zebrina*, however, that may provide the most important difference between the two species. *Z. sericea* are supposedly much larger than males of *Z. zebrina*. Whether or not this is an appropriate character on which to rely for separate species is still to be determined. These problems can only be resolved with a side-by-side comparison of the holotypes of these two nominal species.

Previous distribution records for *Z. sericea* extend as far north as the Democratic Republic of the Congo. East Africa has not been well studied and collections are limited, so the discovery of *Z. sericea* in the Rift Valley and southeastern Kenya may only point to a lack of prior collecting efforts.

Diel Periodicity

Diurnal activity patterns also support identification for *Z. sericea*. All individuals were collected during the middle of the day. Six individuals (five adult males and one immature female) were found on the northeastern shores of Lake Bogoria between the hours of 10:30am and 3:00pm, during the hottest hours of the day. Specimens collected at the Shetani Lava Flow in Tsavo West National Park were also collected between these times. In both locales, the solifuges never stopped for long, running in a zigzag fashion along the rocks. Other workers have also noted this type of behavior in other diurnal solifuges (Hewitt 1921,1935; Lawrence 1928, 1935, 1967a; Pocock 1897; Wharton 1987). Available evidence suggests that this species is diurnal, and it fits the color and shape profile suggested by previous workers for diurnal species (Purcell 1902; Lawrence 1935, 1960, 1963).

Habitat Preferences

Both sites where *Z. sericea* was found contained black volcanic rocks, though the habitats were strikingly different. In Lake Bogoria, for example, *Z. sericea* was found

running on the sides of rocky hill slopes at the edge of the saline lake. The hill slopes had a combination of scrub, black volcanic rocks, bare patches of red clay soil and light colored rocks. *Z. sericea* was observed only to stop on the black rocks, it is assumed to better avoid detection, due to their dark color, which blended perfectly with the black boulders. Whenever *Z. sericea* was on a bare patch or a lighter rock it kept running until it reached a darker spot.

In Tsavo West National Park, however, *Z. sericea* was only found on the sharp, glass-like rocks from the Shetani Lava flow. Several were observed over two days, running over the rocks and beneath the upper crust of the lava flow, making their capture difficult. *Z. sericea* was more conspicuous here than at Lake Bogoria, with their white manes on leg IV. Lawrence (1963) noted that *Z. sericea* looked quite like a grass seed being blown across the ground, and it is noted here that on several occasions a 'capture' of a solifuge turned out to be fluff from nearby dry grasses.

Solpugidae

The distribution of *Zeriassa inflexa* Roewer, 1933 is shown in Figure 22.

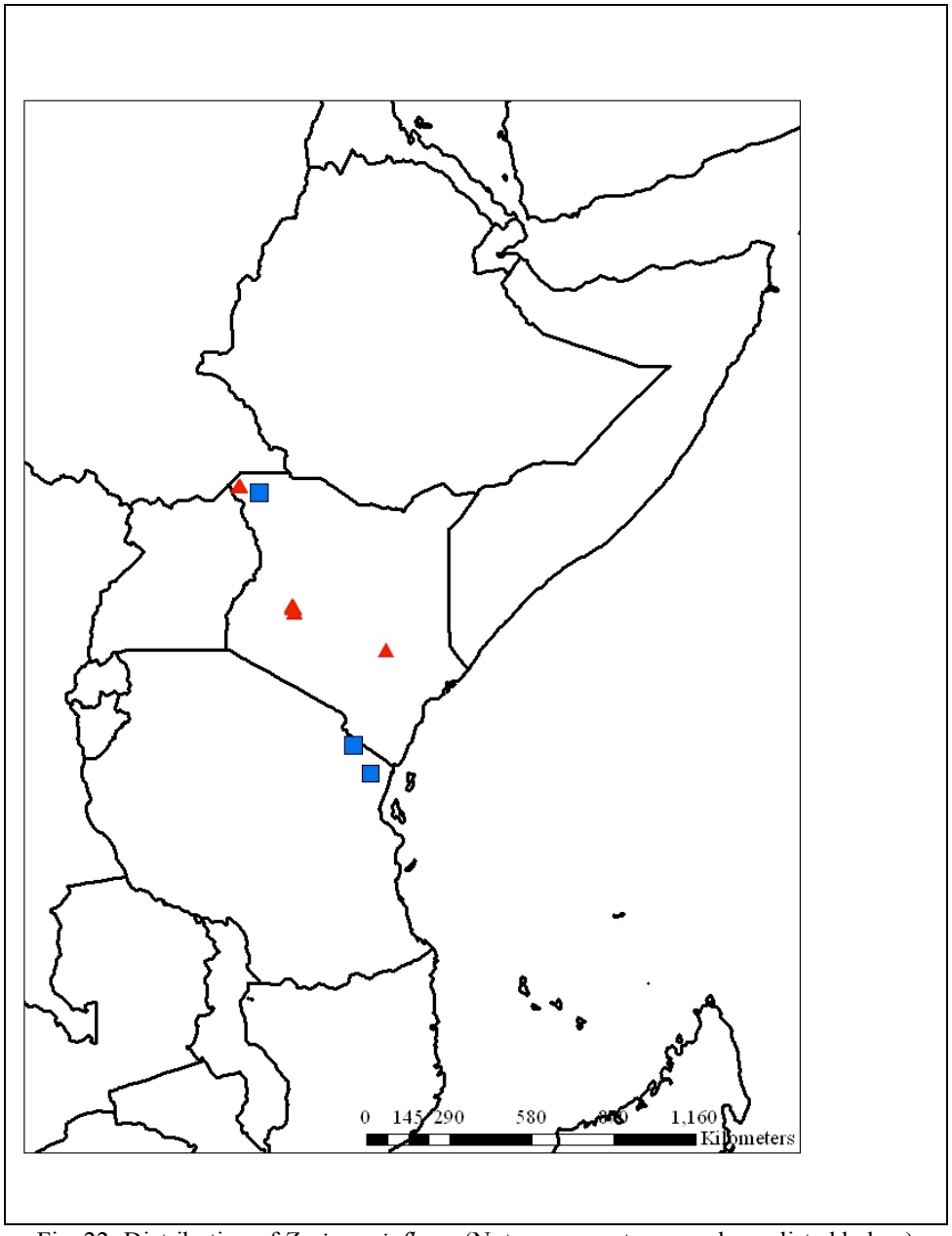

Fig. 22: Distribution of *Zeriassa inflexa*. (Notes on country records are listed below)

KENYA: Coast Province, Kora National Reserve in pitfall traps, 1984, 41 assorted males, females and immatures (NMK); Rift Valley Province, Lake Bogoria National Reserve, 8.VI.06, 0.197500N, 36.108833E, Reddick and Mugambi, 1 female (NMK); Rift Valley Province, Loboii Town, Zakayos Hotel, 0.354444N, 36.064528E, 11-13.II.07, Reddick and Mugambi, 4 males and 4 immatures (NMK); Rift Valley Province, Behind Loboii Town, Kesubo, 0.372306N, 36.070667E, 14.II.07 Reddick and Mugambi, 1 male (NMK); Rift Valley Province, Rd. to Marigat, 0.402110N, 36.020310E, 17.II.07, Reddick and Mugambi, 1 male (NMK); Rift Valley Province, Lake Bogoria National Reserve, 0.217833N, 36.083333E, 26-30.IV.07, Reddick and Mugambi, 1 male, 2 immatures (NMK); Rift Valley Province, Lokichoggio nr. "Camp North," base of Mogila Range, 4.210290N, 34.375740E, 16-17.III.07, Reddick, Wharton and Mugambi, 2 males (NMK).

TANZANIA: Usambara Mountains (Roewer 1933).

Remarks

The nominal subspecies, *Z. inflexa inflexa*, described from Tanzania, and the subspecies *Z. inflexa fuchsi* Lawrence, 1953, which is recorded from Kenya, present some problems in their identification. The flagella of all males collected during this survey, no matter where the locality, are very similar, and the only difference between *Z. inflexa inflexa* and *Z. inflexa fuchsi* is length of the flagellum. In *Z. inflexa inflexa*, the end of the flagellum does not reach beyond the base (Roewer 1933), whereas in *Z. inflexa fuchsi* it extends beyond the base by a tiny amount (Lawrence 1953), but the

difference is almost negligible. The males in this study possess flagella that vary between the lengths of *Z. inflexa inflexa* and *Z. inflexa fuchsi*. However, none of the specimens fit Lawrence's (1953) color descriptions, and all lack the yellow spots at the base of the chelicerae that were deemed an important difference for subspecies identification. In fact, all specimens in this study possess different colors, with the Lokichoggio specimens having yellow bodies, legs and chelicerae, with entirely dark purple pedipalps, and dark purple tergites, and the specimens from Lake Bogoria having almost completely dark purple bodies, legs and chelicerae, of varying degrees of darkness. This suggests that the species may be color variable, with different populations exhibiting different color morphs. While each of these morphs could be designated as a different subspecies, we treat *Z. inflexa* as a single, color-variable species.

Diel Periodicity and Habitat Preference

The species is nocturnal. All specimens, no matter the location, were either collected from under rocks in the daytime, or caught running to lights or stoves at night. All specimens that were found under rocks, no matter the locality, were collected from the sides of rocky slopes with sparse vegetation.

Solpugidae

The distribution of *Zeriassa lepida* Kraepelin, 1914 is shown in Figure 23.

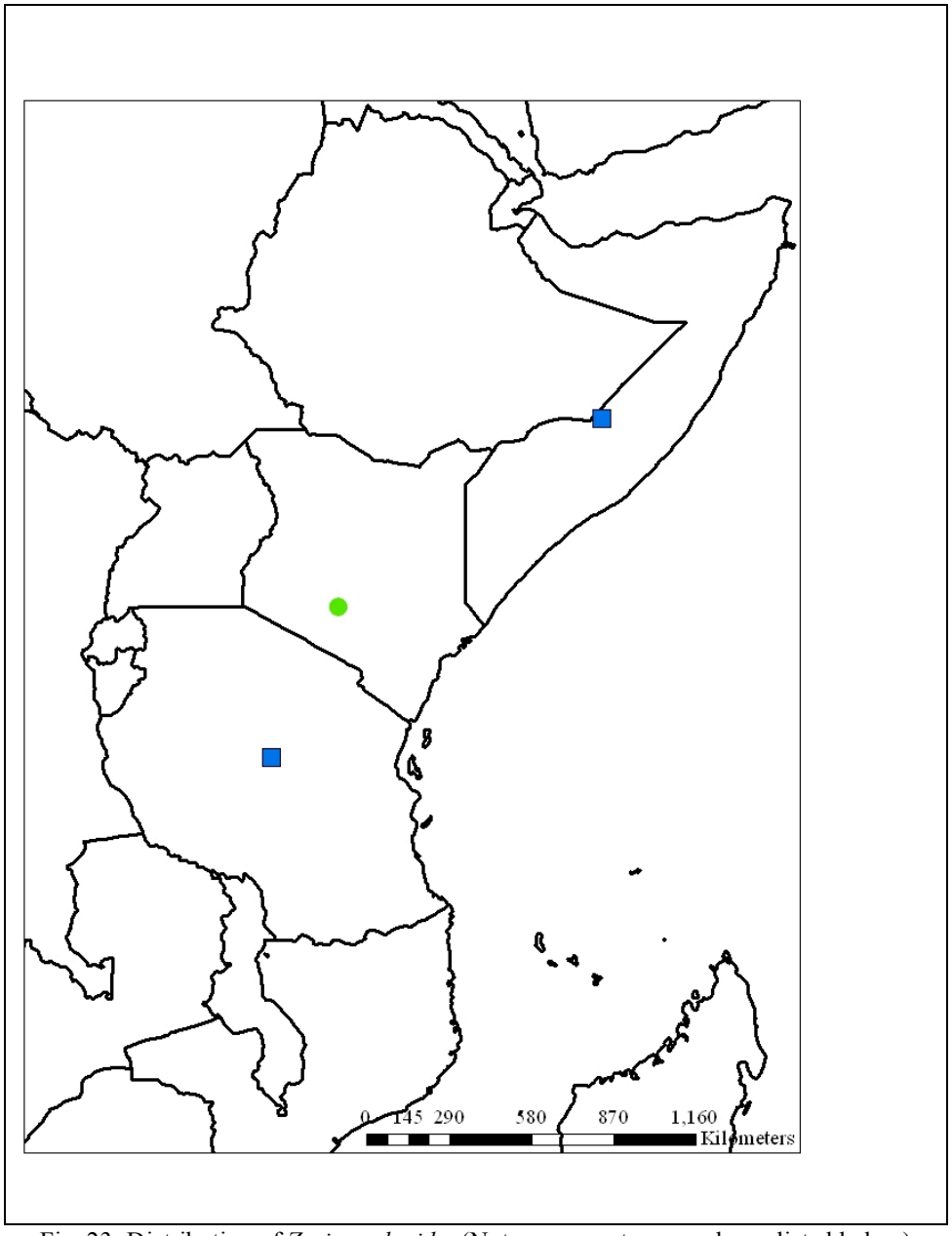

Fig. 23: Distribution of *Zeriassa lepida*. (Notes on country records are listed below)

SOMALIA: Afmadu (Simonetta & Delle Cave 1968).

KENYA: Central Province, NW of Ngong Hills 16.X.1976, 1 male (NMK).

TANZANIA: Kilimatinde, Singida (Kraepelin 1913).

Solpugidae

The distribution of *Zeriassa spinulosa* Pocock, 1898 is shown in Figure 24.

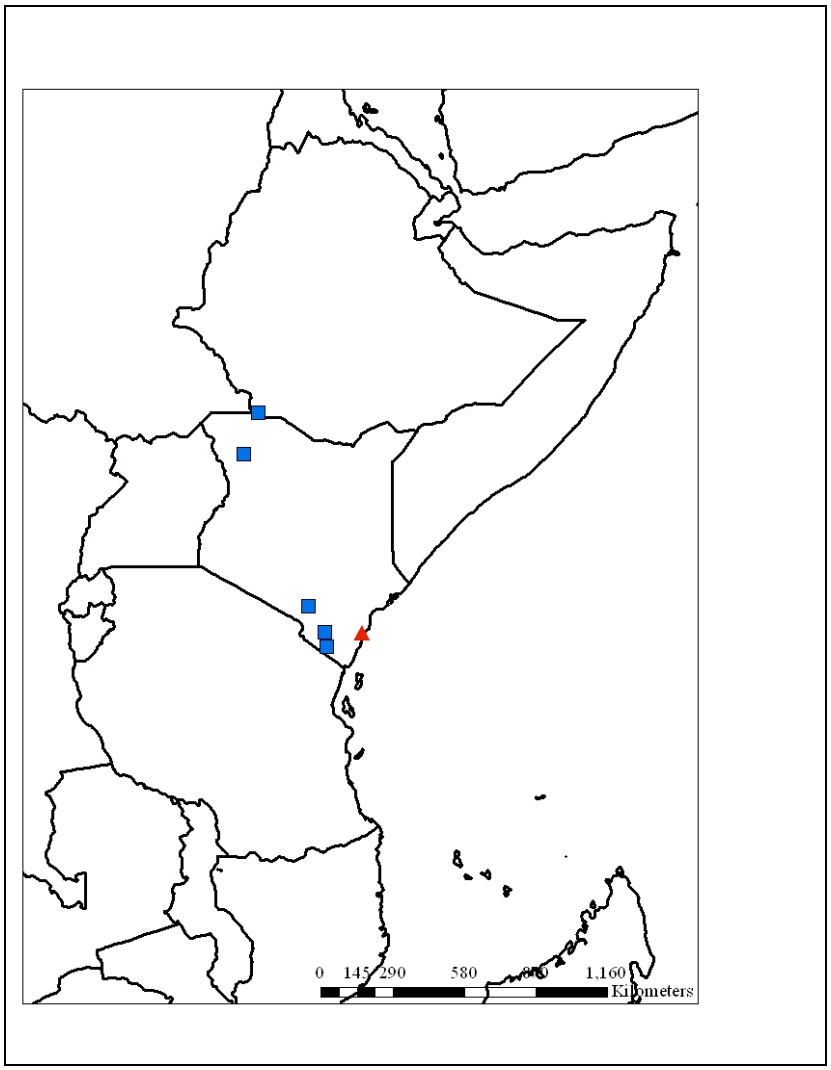

Fig. 24: Distribution of *Zeriassa spinulosa*. (Notes on country records are listed below)

ETHIOPIA: Sidamo Province, Sagan-Omo (Fage & Simon 1936; Caporiacco 1941; Simonetta & Delle Cave 1968).

KENYA: Coast Province, Voi (Birula 1926), Arabuko Sokoke Forest Reserve, -3.421410S, 39.898190E, Reddick, Wharton and Mugambi, 1 male, 1 immature female (NMK); Eastern Province, Kibwezi (Kraepelin 1913, 1914), 15 km. south of Tsavo River (Birula 1926), Maziwa Mitatu, Taru Desert (Pocock 1898); Rift Valley Province, Lodwar (Lawrence 1953).

TANZANIA: Mklama District (Kraepelin 1914)

Remarks

This species was readily identified by its distinctive flagellum. Birula (1926) also cites two other localities in Kenya where this species has been collected, however they are as yet unsubstantiated. The location of "Simba" in Kenya is unknown and may, in fact be "Shimba Hills" simply misspelled and "Buru" Kenya is the name of what is now a Nairobi slum, and this may not be the correct or current name of the locality. Kraepelin (1914) recorded this species from Tanzania, as noted by Birula (1926), but this was apparently overlooked by Harvey (2003).

Diel Periodicity and Habitat Preference

The immature female specimen noted above was collected at 11:30 pm, from a shallow depression along a forest path. The male was collected running toward a light trap also at night. There is no other information available on activity patterns for this species, but these records strongly suggest that it is nocturnal. Both specimens were collected from a coastal forest with sandy soil.

DISCUSSION

New Discoveries and Accomplishments

Prior to this survey, there were 36 species from 12 genera recorded from Kenya. During the six-month sampling period, 116 solifuges were collected, of which 64 were identifiable as species or morphospecies. Two hundred forty solifuges from the NMK holdings were identified to family, 75 of which were identifiable to species. A total of 7 different genera and 19 different species were identified from both the NMK holdings and newly collected material. Two genera, *Tarabulida* and *Solpugyla,* and 9 species (6 of them apparently undescribed) were newly recorded from Kenya in this study. In addition, the *Tarabulida* specimen from Lokichoggio is the first male ever recorded for the genus. Three new species records for Kenya were added: *Z. sericea, Z. lobatula* and *Z. meruensis.* Six apparently undescribed species were recorded from Kenya as a result of this survey, including five unidentified rhagodids and the *Tarabulida* species. The southernmost locality record for Galeodidae and *Galeodes arabs arabs* was uncovered in the NMK holdings. In addition, the first solifuges recorded from the Mara ecosystem were collected during this study, though they could not be identified past family (Solpugidae) because they were immature females.

Habitat

Kenya's varied habitats may hold the answer to the higher family level diversity found in the region as opposed to surrounding countries. Solifuges in the study were found in several strikingly different habitats from the Shetani Lava Flow in Tsavo West National Park (*Z. sericea*) to incredibly humid coastal forests (*Z. nasuta* and *Z. spinulosa*) to the arid north west (unknown Rhagodidae) to the shores of an ultra-alkaline saline lake (*B. velox velox*, *Z. inflexa inflexa*, *Z. fordi*, and unidentified *Hemiblossia*) to Nairobi City (*Hemiblossia brunnea*). Even though the majority of Kenya is arid/semi-arid land, the diversity between and within habitats is astounding. Recognizing this variation in habitats and ultimately, more important, microhabitats within the same area is an important step toward targeting future surveys in East Africa.

Based on historical records and the data collected during this survey, there are several regions of the country that stand out as having the highest concentrations of solifuges: the Lake Bogoria/Baringo area, the Samburu region east to Kora National Reserve, and the Turkana region. However, there are several areas that are almost entirely unexplored due to political instability, like the northeastern section of the country that could possibly have high concentrations of solifuges as well.

There were several places in Kenya that should have been overflowing with solifuges, due to the habitat quality and type. For example, Lokichoggio, in the north-west corner of Kenya is rocky and arid. However, Galeodidae were not collected there during the study, and we found relatively few solifuge individuals during two days and two nights of intensive collecting. This may be the result of collecting during the wrong

time of year, or just poor timing since the entire area was subjected to massive floods a few days before we arrived. However, we know from historical records that northwestern Kenya in the Turkana area is an area that supports several different species of solifuges.

By the same token, solifuges were found in habitats where they were not expected, as in the humid coastal forest. Since solifuges are often thought of as arid/semi-arid dwelling animals, it was surprising to find two species (*Z. nasuta* and *Z. spinulosa*) during our very short time on the coast. Both species were found on sandy soils in or near the forest, so this could point to a very specific microhabitat preference, as other areas were sampled nearby and no solifuges were found.

Kenya as a Transition Zone

The area of Kenya north of the equator is the only place in Africa where Galeodidae, Solpugidae, Ceromidae, Rhagodidae and Daesiidae can be found to co-exist. There is no evidence of Gylippidae in Kenya, even from the unidentified material collected over a hundred year period in the holdings of NMK. This most likely means that endemic genera of gylippids from southern Africa are truly isolated from Gylippidae occurring in the Middle East and Asia, and likely represent a different evolutionary lineage (possibly not even of the same family). Similarly, we found no evidence of either Hexisopodidae or Melanoblossidae in Kenya, suggesting that these may indeed be southern African endemics.

On a generic level, Birula (1926) hypothesized that the Kilimanjaro region in northern Tanzania would be a natural barrier to northern expansion for genera, like

Ceroma, Solpuga and Daesia (now *Biton*) that are found in abundance in southern Africa and a barrier to southern expansion of the Palearctic genera *Galeodes, Rhagodes, Paragaleodes* and *Gluviopsis*. In some respects, he was correct, but the presence of two species of *Solpuga* and one species of *Ceroma* extending north of Kilimanjaro and into Kenya means that Kilimanjaro is not a complete barrier.

One problem with assigning distribution to species and genera is the changing of names that has taken place following independence of several African countries. Many species are described from places whose names no longer exist. For example, the countries of Somalia, Eritrea and parts of Ethiopia were once known as Italian East Africa. During the short colonization of these areas, many solifuges were described using the Italian names for locale. When independence was gained, as happened in much of Africa, traditional tribal names for regions and towns were resurrected, and are used in modern maps. This confusion, along with repeated names (e.g. Meru, Kenya and Mt. Meru, Tanzania) adds to the problems associated with completing a picture of solifuge geographic distribution.

Diel Periodicity and Diurnal Activity

For the most part, solifuges are nocturnal or exhibit crepuscular activity patterns (Pocock 1898; Cloudsley-Thompson 1977). Diurnal activity patterns have been noted, but are often ignored in general accounts. Most solifuges in North America, for example, are nocturnal, but a few individuals of two genera, *Hemerotrecha* Banks, 1903 and *Eremochelis* Roewer, 1934 are diurnal.

Published reports of diurnal solifuges in Africa have almost exclusively come from the southern part of the continent (Pocock 1897; Purcell 1902; Lawrence 1928; Hewitt 1935; Wharton 1987) suggesting that diurnal solifuges are restricted to southern Africa (Lawrence 1963; Wharton 1987). Our study has shown that this is not the case. One species of solifuge found in Kenya during this study, *Z. sericea*, was found to exhibit diurnal behavior in two different localities. All specimens were active during the day, and are therefore diurnal. One species in Kenya is definitely diurnal, with two more showing signs of diurnal activity, while five species are known to be nocturnal or crepuscular from this study. Since this leaves at least 29 species in Kenya alone whose daily activity patterns are still unknown, future collecting in eastern Africa should reveal more species exhibiting diurnal activity patterns. In this regard, we predict that *Z. zebrina* is also diurnal, based on its morphological similarity to *Z. sericea*. It may ultimately be possible to split *Zeria* into nocturnal and diurnal species, as *Z. sericea*, *Z. celeripes* Hirst, 1911, and *Z. caffra* Pocock, 1897 have all been confirmed as diurnal (Hewitt 1921; Lawrence 1967a), while a large number of species now placed in *Zeria* are nocturnal (Lawrence 1967a).

In southern Africa, *Solpuga bechuanica* Hewitt, 1914 has also been described as active during the day, as have species of *Hemiblossia*, *Solpugema*, and other species of *Solpuga* s. s. There is thus some evidence, both in North America and in Africa, that diurnal solifuges may belong to distinct taxonomic units. Detailed biological studies are needed to uncover the patterns, however, since individual records of diurnal activity patterns may not be enough evidence to label a solifuge as diurnal. More extensive

biological work needs to be completed, like Wharton's (1987) work on the diurnal *Metasolpuga picta*, in order to establish if a solifuge is indeed strictly diurnal, or simply spooked during the day into running for shelter.

Species Identification

Roewer's keys are notoriously difficult to use and his descriptions are inadequate or based on dubious characters that exhibit extreme variation from individual to individual. His reliance on the spination patterns of the tarsi to determine genera is one of the most frustrating problems, because often spines are broken, or may become damaged and not be present after a molt. Often leg spination differs not just between different specimens, but also on a single specimen. Some variation may be on account of certain unknown behaviors, for example the possibility that rhagodids may dig more than other solifuges. If they do in fact use their legs to dig into the ground, as discussed previously, this could lead to spine breakage, and the reason workers in the past have seen such variation in chaetotaxy of the tarsi, which may have contributed to the description of inordinate numbers of monophyletic genera.

There are other characters that also cause problems. One character that is incredibly difficult to determine is the cuneiform deuterosternum of *Zeriassa*. This character, when encountered in a key can often lead to misidentifications. Many previous workers have mentioned these difficulties (Lawrence 1955; Muma 1951, 1970; Panouse 1961a/b) and attempted to rely on other characters like color or size, which are equally problematic.

Reliance on the flagellum is often a problem with solifuge identification. It restricts identification to males and is confounded by the inconsisntent or inadequate drawings of people who have described and redescribed species based on this one morphological character. On the other hand, the flagellum is one of the best characters for species-level identification of most African Solifugae. In this study, the distinctive flagella of *B. velox velox* , *B. tigrinus*, and *H. brunnea* aided in their identification, as did the flagella of *Z. fordi*, *Z. nasuta* and *Z. meruensis*. Also, when you find a specimen with an incredibly unusual flagellum like that of *Tarabulida,* it is a useful tool to help determine new species.

Even when a worker is confident about the identification of a mature male solifuge, problems arise with females. In this study a large number of females were not capable of being identified. Many of these could have been tentatively identified, at least to genus, but I am hesitant to add to the rampant problems of misidentifications throughout the history of solifuge research. There is extreme difficulty in matching females with males in all families of Solifugae (Simonetta & Delle Cave 1968). This is due to the propensity for reliance on variable characters, such as dentition, which can vary between sexes and ages, coloration and a long history of mismatched males and females. Often, as in the case of *Tarabulida,* Roewer described genera and species from females only.

Given these uncertainties, we take a conservative approach to the identification of new genera and species. As in the case of the *Tarabulida* found in this study, there were some differences between the types (females) of the two species previously

included in the genus and the male specimen collected, most notably coloration and chaetotaxy of the pedipalps. A less conservative approach may be justified in naming a new genus, since several new genera have been described for the Solifugae based on less distinct differences. However, I believe that a conservative approach when it comes to the grouping of solifuges is in order, as monotypic genera and singular species accounts in many families will most likely need to be revised and combined in the coming years. An example of this would be the Rhagodidae; 13 of 27 genera are monotypic, and several others have only two or three described species. It will be easier in the future to separate obvious differences in species using both morphology and DNA, than to constantly synonomize existing taxa.

Future Work

It would be incredibly helpful for future solifuge workers, if collectors make note of the habitat type in which solifuges are found during their studies. There have been some notes on habitat preference on a microhabitat level (Lawrence 1955; Punzo 1998; Wharton 1987; Dean & Griffin 1993). Muma (1974a, 1979) has provided some of the most extensive work on habitat associations and comparisons, however there is almost no data on the exact type of habitat where most solifuges are found. This would be helpful for locating rhagodids and ceromids and will provide useful biological and ecological information.

In general, more collecting needs to be done in areas of central and eastern Africa. Until political and social unrest in the region stabilizes, further collecting on a large scale will have to be put on hold. However, with the training received during this

survey, researchers at the NMK now have tools to identify solifuges to family level, which will undoubtedly increase the knowledge of fauna in the country. If political unrest were not a problem, the north of Kenya near Somalia, Ethiopia and Sudan would be worth concentrating on, as little to no collecting has been done in these areas.

While Kenya did not prove to possess the highest diversity of African solifuges, for a small, relatively poorly sampled country, the family diversity is among the highest in Africa. Namibia and South Africa have 6 families each, but both are much larger than Kenya and much better sampled. Similarly, Ethiopia and Sudan probably have the same families of Solifugae as Kenya, but are very large and poorly sampled. With additional collecting in Kenya, particularly in northern Kenya, the Lake Bogoria Region and the Samburu area, the species diversity is likely to be quite high.

CHAPTER III

SOLIFUGE TROPHIC POSITION IN DESERT COMMUNITIES

INTRODUCTION

It is widely recognized that solifuges are important inter- and intraguild predators in arid and semi-arid ecosystems, but their role as a prey animal is not well understood. The present studies serve to provide data on the roles of solifuges as both predators and prey. The first is a feeding study and provides insight into whether or not there is a preference in solifuges toward hard or toxic prey. The second study, involving the quantification of arthropod remains from burrowing owl pellets in the southwestern United States, determines prey preference among six orders of arthropods, including solifuges.

Solifuges as Predators

Most of the species of solifuges that have been examined in any detail are capable of consuming a wide range of prey items, mostly insects and other arachnids such as spiders. Muma (1966b) and Cloudsley-Thompson (1977) briefly summarize previous observations and provide extensive citations to the earlier literature on prey items and feeding behavior. There are many dubious records of solifuges eating abnormal prey, such as vertebrates. Hutton (1843) provided one of the first such records when he reported a species of *Galeodes* killing and burying a young sparrow and young muskrats.

Much of the information on solifuge predation is comprised of anecdotal stories and singular events observed in the field. However, Muma (1966b) and Punzo (1993,

1994a/b, 1997) provide good experimental data and some field observations on prey choice and feeding behavior for several species of Eremobatidae and a few Ammotrechidae from southwestern USA.

Muma (1966b) conducted several different kinds of general feeding experiments on North American Solifugae that covered a wide range of feeding behaviors: engorgement, starvation, water ingestion, communal feeding, cannabalism, and food preference. Muma confirmed that solifuges use a variety of different behaviors when capturing their prey, including striking with the chelicerae, using the pedipalps to pull prey to the chelicerae, and lie-in-wait ambush and further that the type of strikes may be correlated to the size of prey handled. He observed more extensive use of pedipalps with increasing prey size. Immatures and males of three species of *Eremobates* and one species of *Eremochelis* Roewer, 1934 survived up to three weeks when denied food; others survived up to 10 weeks while refusing food that was offered.

Based on his studies of eremobatids, Muma (1982) concluded that while adults are generalist predators, most feed on termites, and that immatures feed primarily on termites. Additionally, there are several records of termitophilous species from other solifuge families, and members of the Old World genus *Hemiblossia* (Daesiidae) have been frequently collected from termite mounds or among foraging columns (Lawrence 1963). Punzo however, did not find termites among the 111 dietary items he identified from his observations on actively foraging eremobatids. His data nevertheless do provide solid evidence of a broad diet for the two species of *Eremobates* that he studied. The most common prey items for *E. mormonus* and *E. palpisetulosus* Fichter, 1941

include Orthoptera, spiders, Lepidoptera, and Coleoptera while chemically defended animals like scorpions, millipedes, velvet ants and blister beetles were avoided.

Both Muma (1966b) and Punzo (1993, 1994a, b, 1998) demonstrated that at least some solifuges rejected prey items that were either too large, too heavily sclerotized, or which may have been protected by defensive chemicals. Other solifuges, however, did not. Due to the shortcomings and challenges associated with previous feeding studies of solifuges, one objective of this study is to provide baseline data on the ability of solifuges to handle hard and toxic prey, and whether there is a preference for one over the other.

Solifuges as Prey

Though solifuges are most often thought of as predators, they may also be an important supplement to the diets of many animals found in arid and semi-arid ecosystems. Whether or not solifuges are an important proportion in the diets of arid-dwelling mammals, birds and reptiles is not well understood. To date, there are only a few regional studies on predators of solifuges, and, unlike the summaries of Muma (1966b), Cloudsley-Thompson (1977) and Punzo (1993, 1994b) for solifuges as predators, there are no publications that collate data on solifuges as prey. A search through literature on individual biologies of desert animals does provide some clue as to the role of solifuges in arid ecosystem food webs, but whether or not they are critically important as a preferred food source during certain seasons is, at this point, undetermined. Pellet, scat and stomach analyses from various studies provide the most detailed accounts of predation on solifuges to date and most of the quantitative data

comes from Africa. One problem for quantification of solifuges in vertebrate diets may be linked to identification, as all arachnids or even all invertebrates are sometimes lumped as a single category during feeding studies for vertebrates.

Birds, small mammals, reptiles and arachnids such as spiders are the animals most frequently recorded as predators of solifuges. Arthropod predators of solifuges are not easily quantified because often it is not clear whether the solifuges involved were targeted as prey or simply unlucky in their role as predator. One clear record of an arthropod predator of solifuges comes from Namibia, involving a sparassid (Araneae) observed capturing and eating a male *Metasolpuga picta* (Wharton 1987). Almost every anecdotal account of solifuges includes stories of vicious fights between solifuges and scorpions. Most of these accounts are due to human influence in pitting these animals against each other.

Reptiles are common in every arid habitat in the world, however records of solifuges in desert reptile diets are scarce. There have been a few studies on diets of North American reptiles that include solifuges as prey. Nocturnal solifuges were found to be the fourth most abundant prey item of *Coleonyx brevis* Stejneger, 1893, a species of gecko found in the Chihuahuan Desert, after termites, cicadellids and spiders (Dial, 1978). Side-blotched lizards (*Uta stansburiana* Baird, 1852) from south-eastern New Mexico have also been recorded to prey on solifuges (Best & Gennaro 1984). Most reports on African reptiles and amphibians eating solifuges are either anecdotal or unpublished.

Several small mammals include solifuges in their diets as evidenced by scat analysis and stomach content analysis. For example, solifuges comprised the highest percent prey of 13 long-eared desert bats (*Otonycteris hemprichi* Peters, 1859) in Kirghizstan during a fecal sample analysis (Arlettaz et al. 1995). There are very few quantifiable accounts of solifuge predation for the continent of Africa, as many of the counts are observational in nature. Exceptions in this regard are the detailed analyses presented in Smithers (1971), and individual records from scat analysis for the common genet (*Genetta genetta* Linnaeus, 1758) (Viljoen & Davis 1973), silver fox (*Vulpes chama*, Smith 1833) (Bothma 1966), African civet (*Viverra civetta*, Schreber 1776) (Bothma 1971), Blanford's fox (*Vulpes cana* Blanford, 1877) (Geffen et al. 1992) and the black-backed jackal (*Canis mesomelas* Schreber, 1775) (Stuart 1976). Usually, data come from targeted single-species feeding accounts where solifuges may not register in abstracting services, which makes the compilation of such data arduous.

Several studies suggest that raptors may be the most common bird predators associated with large solifuges in southern Africa. Kopij (2002), for example, found that solifuges were the most important food source in November and December for lesser kestrels (*Falco naumanni* Fleischer, 1818) wintering in South Africa, comprising over 70% of the total prey consumed. Similarly, Anderson et al. (1998) examined the stomach contents of 229 lesser kestrels from two airports in South Africa and concluded that solifuges were the most frequent prey in the arthropod diet at 30%. Lesser kestrels forage in the morning and afternoon and the solifuges found in the study were found to be much more abundant in the afternoon, an indication that the solifuges preyed on by

the lesser kestrel are diurnal. Wharton (1987) also found cheliceral remains in bustard droppings and kestrel pellets in Namibia.

Solifuges have been recorded as prey of many different species of owl. Some findings are not elaborate, like records of marsh owls (*Asio capensis* Smith, 1834) eating 2 solifuges during a study in northwestern Namibia (Braine 1989), but some show extensive solifuge predation. Obuch and Kristin (2004) calculated that solifuges in Egypt, Iran and Syria make up 4-11.4% of total diet of little owls (*Athene noctua* Brehm, 1855) in extreme deserts, calling them a characteristic component of food in arid ecosystems. Little owls in Iran had the highest percentage of solifuges in their diet, mostly from the family Solpugidae. The solifuges found in these studies were also some of the largest invertebrates in the diet of the little owl.

Burrowing owls are one of the few species of New World owls known to eat solifuges (Moulton 2005). Several additional studies on diet of burrowing owl have been conducted (Marti 1974; Thomsen 1971; Schlatter et al. 1980), but solifuges have not always been recorded in the diet. Schlatter et al. (1980), for example, dissected 770 pellets from burrowing owls near Santiago, Chile. They found that beetles and dragonflies dominated the insect portion of the arthropod diet. Arachnids were found to make up a negligible percentage of arthropod prey throughout the study and no solifuges were found in the pellets. There are two families of solifuge, Daesiidae and Mummuciidae, recorded from localities around Santiago, Chile (Harvey, 2003), but it may have been the wrong time of year for seasonal solifuges that live at a high elevation.

They concluded that burrowing owls eat mainly ground dwelling arthropods, or highly mobile insects like dragonflies that go into torpor at night when temperatures plummet.

The second objective, using burrowing owl data from Tucson, Arizona, is to quantify solifuges as prey, and examine their importance in desert trophic systems. These results, combined with those from the aforementioned feeding study, provide much needed baseline data that will support future work on the placement and importance of solifuge arachnids in desert trophic interactions.

MATERIALS AND METHODS

Solifuges as Predators: Solifuge Feeding Study

The solifuge feeding study was conducted in Kenya at the Lake Bogoria Dry-land Environmental Education Center (0.348930N, 36.062510E) and all solifuges were collected for the experiment inside the Lake Bogoria National Reserve boundaries. The study took place over 6 nights from 27.iv.2007- 2.v.2007. This reserve was chosen for the feeding study because of the likelihood of being able to locate enough solifuges for the study, since this area of Kenya had been surveyed twice before, and locations of preferred habitats had therefore already been established. Even in this case, it was impossible to find multiple large solifuges of the same species, so certain parameters were modified to match the unique needs of each specimen collected, i.e. size of prey animals offered, cage size, etc. Numbers of specimens (in parentheses) and species used in the study were as follows: unidentifiable immature *Biton* spp. (2), *Biton velox* (3), un-described *Hemiblossia* sp. (1), unidentifiable immature Solpugidae (4), *Zeria fordi* (5),

and *Zeriassa inflexa* (2). Three different types of containers were used to hold the solifuges: plastic Ziploc® containers for extremely small solifuges, 1-liter water bottles turned on their sides for small-medium solifuges, and plastic terrarium cages for larger solifuges.

All solifuges tested in the study were nocturnal. Solifuges were collected by hand during the day from under rocks and starved for a period of 24 hours. Termite workers (a species of *Macrotermes* Holmgren, 1909) were used as a 'behavioral check' in this study, and fed to the solifuge being tested before and after each hard or toxic prey item was offered to ensure that the solifuges were willing and able to feed. *Macrotermes* workers come in a range of sizes suited to the range of solifuges used in the experiment. Termites are known to be readily consumed by solifuges in the wild and are readily accepted prey items in laboratory settings (Muma 1966b). This proved very important as a gauge for normal behavior, as it has been documented (Muma 1966b; Punzo 1998) that solifuges often do not eat in caged conditions, and often display abnormal behaviors indicating high levels of stress, such as rapidly running around the cage to the point of exhaustion or repeated attempts at escape using the suctorial organs on the ends of the pedipalps. Termites offered and percentages eaten on a daily basis were quantified for each solifuge in the study.

Solifuges were offered a total of five prey animals each night of the study in the following order: termite, hard, termite, toxic, termite. Prey animals were dropped into each cage through openings on the top, regardless of whether or not the solifuges were active. Each solifuge had ten minutes to eat the proffered food. All behaviors were

noted, with the following specifics recorded for analytical purposes: 1) prey item eaten or not; 2) if eaten, whether partially or completely; 3) if not eaten, was an attempt made to eat it or was it completely ignored/avoided; 4) prey item overpowered, killed, or injured solifuge. Any abnormal behavior exhibited by the solifuges, such as that noted in the previous paragraph, was also recorded. All solifuges were fed over an equal number of days, with the exception of those that died mid-experiment or were killed by prey species.

To determine whether solifuges are constrained with respect to their abilities as predators, two types of prey items were offered: ones that were heavily sclerotized and ones that were potentially toxic. Two types of hard prey were offered, a flat tenebrionid in the genus *Tenebrio* Linnaeus, 1758, and an unidentified species of long-legged tenebrionid with sealed elytra, which are presumed difficult, though not impossible, for solifuges to eat (Wharton 1987). To ensure that the unidentified tenebrionids did not possess repugnatory chemicals, as are found in similarly sized and shaped *Eleodes* Eschscholtz, 1829 from the southwestern United States, the beetles were rolled between our hands and some were mashed. No evidence of repellant chemicals was found. These two species offered a more complete picture of the body types that could or could not be opened by the solifuges, whether large or small. Beetles range in cuticular hardness from soft and pliable, as in the case of soldier beetles (Coleoptera: Cantharidae) to relatively hard in taxa like tiger beetles of the genus *Cicindela* Linnaeus 1758, to extremely hard beetles as in the case of the tenebrionid species chosen for this experiment. Toxic species offered were *Danaus chryssipus* Linnaeus, 1758 butterfly

pupae that contain pyrrolizidine alkaloids (Edgar et al. 1979), polydesmid, or flat, millipedes that contain the cyanogenic toxins phenol and guaiacol (Duffey et al. 1977) and *Pachycondyla* sp. Smith, 1858, ants that leak bitter tasting cyclic dipeptides (Morgan et al. 2003). Mobile toxic prey (ants and millipedes) were offered in addition to pupae because of the pupa's inability to move and previous studies indicate solifuge attacks may be influenced by prey movement (Punzo, 1998). Butterfly pupae were purchased from the Kipepeo Butterfly Project on the coast. Termites, ants and beetles were collected from the same areas as solifuges used in the study, in and around the Lake Bogoria National Reserve. Voucher specimens for prey animals were deposited in NMK Division of Invertebrate Zoology. All solifuges were used in the analysis, regardless of whether or not they ate termites.

All statistical analyses for the feeding study were run in SAS Data were only used from the first three days of the study, even though further data were obtained, due to the fact that the sample size of solifuges (*n*) in the study decreased over time because of solifuge fatalities. . Two Goodness-of-Fit tests (Deviance and Pearson) were run to determine if logistical regression was appropriate. Logistic regression was used due to the binomial characters in the dataset (0=no ingestion, 1=ingestion). The following logistic regression model was used:

$$Y_i = \tau_0 + HARD\_TOXIC_i + DAY_i$$

where: Y= response (0/1), τ= effect, because the model assumes three effects: the mean effect (general mean/baseline value), the HARD_TOXIC effect (Factor 1), and the DAY effect (Factor 2). The hypothesis behind the use of this model is that the choosing of

hard or toxic prey (Factor 1) will affect the response, and that the experiment response will be different if we look at a different day (Factor 2). For example, a positive regression for Factor 1 will mean that if you feed a solifuge different prey (hard or toxic) the response will be different. In order to test the hypotheses for both factors a Wald Statistic was used:

$$\frac{\left(\hat{\theta}-\theta_0\right)^2}{\mathrm{var}\left(\hat{\theta}\right)}$$

where $\hat{\theta}$, the maximum likelihood estimate, is compared to θ_0 , the proposed value. The value obtained is compared to a chi-square distribution table where $\alpha < .05$. θ in this test was calculated automatically in SAS. The logistic regression model and Wald test only told us whether or not each factor mattered. In order to determine if preference existed between hard and toxic food, an odd ratio estimate was calculated:

$$\frac{\theta}{1-\theta}$$

where θ represents the probability of eating hard food. The probability of eating toxic food is then calculated by subtracting θ from 100. Again, the value for θ for this test was calculated automatically in SAS.

Solifuges as Prey: Burrowing Owl Feeding Study

In order to quantify the role of solifuges as prey in desert communities, 625 burrowing owl pellets from 290 burrows were examined for invertebrate prey composition. Pellets were obtained from the Davis Monthan Air Force Base (DMAB) in Tuscon, AZ (32.157446N, 110.840783W), and were collected from 2.v.02-31.viii.06 by the Arizona Game and Fish Department (AZGFD). Vertebrate remains in the pellets

were separated and quantified by the AZGFD before shipment for this study. Each pellet was examined for invertebrate parts. Approximations were used for a whole count of animals, for example, one pair of mandibles of lepidopteran larvae were quantified as one animal, as was one unpaired mandible. In the case of solifuges, dorsal and ventral chelicerae were matched to create an accurate picture of solifuges per pellet. Invertebrates were identified to order and wherever possible, genus and species.

Thomsen (1971) reported that burrowing owls have a tendency to pick at their food, often saving part of their prey for later. This makes it difficult to quantify number of prey items eaten when using individual pellets as the data source. However, it is still possible to calculate the presence or absence of particular prey items in the pellets and compare the total proportions in much the same way as a means comparison. Thus, for this analysis, proportions of pellets containing the six most commonly encountered orders of arthropods were compared (e.g. 372 pellets out of 625 total contained solifuge remains). A contingency table approach was used to test the homogeneity of proportions of different prey in the owl pellets. The critical value was obtained from a chi-square distribution table at $\alpha = .05$:

$$x^2 = \sum \frac{(f_o - f_c)}{f_c}$$ where f_o = observed frequency, f_c = expected frequency.

The Marascuilo Procedure for pair-wise comparison between individual proportions was then calculated to determine which proportions were statistically different:

$$y_{ij} = \sqrt{x^2\alpha, k-1}\sqrt{\left(\frac{p_i(1-p_i)}{n_i} + \frac{p_j(1-p_j)}{n_j}\right)}$$ where α = .05.

Field Observations

Additional, non-quantitative observations were made during collection of solifuges for this and other studies (see Chapter II). When predation on solifuges was observed, identities of predator and prey species were determined as precisely as possible.

RESULTS

Feeding Study

Prey items offered and frequencies of ingestion are given in Table 2; for purposes of analysis all prey items (except termites) were categorized as either HARD or TOXIC. The p-values for the Deviance and Pearson Goodness-of-Fit models are 0.22 and 0.33 respectively (Table 3), indicating that the regression model was appropriate for the data. Results for the Wald statistic are shown in Table 4. The p-value of the Day effect is very large at 0.79, which means that the day the solifuges were fed was an insignificant factor in whether or not the solifuges ate. The HARD_TOXIC effect is also not significant. The results for the odds ratio estimate are shown in Table 5, with θ = 0.28, the probability of eating hard food, leaving 0.72 as the probability of eating toxic food. This indicates that solifuges are more likely, or able, to eat toxic prey than hard prey. Termites were eaten repeatedly by 16 of the 17 solifuges in the study (Table 1), but only 3 of the 17 solifuges

in the study ate hard or toxic prey that was offered. By the final day of the study there were only 3 solifuges left alive.

Table 2: Prey items offered and eaten. Stage and sex of solifuge: I=immature, sex undetermined, IF=immature female, IM=immature male, MM=mature male; O=offered, E=eaten. No values indicate that the solifuges died before being offered prey.

	Stage & Sex	Hard				Toxic						Termites	
		Tenebrio		Tenebrionid		Polydesmidae		Danaus pupae		Pachycondyla		Macrotermes	
		O	E	O	E	O	E	O	E	O	E	O	E
Biton sp.	I	3	0	3	0	-	-	1	0	-	-	18	5
Biton velox velox	IF	2	0	1	0	1	0	1	0	1	0	9	1
Biton velox velox	I	1	0	2	0	2	0	-	-	1	0	8	2
Biton velox velox	MM	-	-	2	0	1	0	1	0	-	-	6	2
Hemiblossia sp.	I	1	0	1	0	-	-	1	0	1	0	6	2
Unidentified daesiid	I	2	0	1	0	1	0	-	-	2	0	9	3
Unidentified solpugid	I	2	0	3	0	2	0	1	0	2	0	14	8
Unidentified solpugid	I	2	0	3	0	2	0	1	0	2	0	14	7
Unidentified solpugid	I	1	0	1	0	-	-	-	-	-	-	8	6
Unidentified solpugid	I	3	0	3	0	2	0	2	0	2	0	18	12
Zeria fordi	IF	3	3	3	2	2	2	1	1	3	2	18	18
Zeria fordi	IM	3	1	2	0	2	2	2	2	1	1	15	9
Zeria fordi	MM	-	-	1	0	-	-	1	0	-	-	2	1
Zeria fordi	MM	1	0	-	-	-	-	1	0	-	-	3	3
Zeria fordi	MM	2	2	3	0	2	2	1	1	2	2	15	13
Zeriassa inflexa	IF	-	-	1	0	-	-	1	0	-	-	3	0
Zeriassa inflexa	IF	1	0	2	0	-	-	1	0	2	0	9	3

Table 3: Deviance and Pearson Goodness of Fit statistics

Criterion	DF	Value	Value/DF	P> Chi-Sq.
Deviance	2	2.9707	1.4853	0.2264
Pearson	2	2.1909	1.0955	0.3344

Table 4: Wald test: Analysis of effects

Effect	DF	Chi-Square	Pr > Chi-sq.
Hard_Toxic	1	1.7252	0.1890
Day	2	0.4736	0.7892

Table 5: Odds ratio estimates

Effect		Point Estimates	95% Wald Conf. Limits
Hard_Toxic	H vs. T	*0.384	0.092 – 1.602
Day	1 vs. 3	0.672	0.122 – 3.718
Day	2 vs. 3	1.171	0.230 – 5.960

Burrowing Owl Study

Tables 6 and 7 show the frequency of occurrence and the approximate number of prey for each of the different prey taxa found in a total of 625 pellets. Lepidoptera and Coleoptera had the highest frequency of occurrence. While coleopterans were the most frequent prey consumed (found in 81.2% of pellets), they were second in total numbers of individuals consumed to Lepidoptera. Solifuges were the third most frequent prey item consumed by the owls at 59.5% and were ranked as the third most numerous prey items in the diet. Orthopterans were the fourth most numerous and frequent prey items,

with Acrididae having the most representation in the order. Table 6 shows the mean per total pellet numbers of the six most commonly encountered arthropod orders in the pellets.

Table 6: Food of burrowing owls in the Davis-Monathan Air Force Base, Tucson, Arizona. Data are from pellets collected from February 2002 to August 2006.

	Frequency of Occurrence in 625 Pellets		**Total Number of Prey Individuals in 625 Pellets**	
Taxa	N	%	N	%
Arachnida				
Solifugae	372	59.5	714	17.3
Scorpiones	196	31.3	120	2.9
Insecta				
Orthoptera				
Combined	282	45.1	237	5.7
Gryllidae			2	.02
Acrididae			235	5.7
Coleoptera				
Combined	508	81.2	1006	24.5
Scarabaeidae			215	5.2
Carabidae			185	4.5
Silphidae			8	.19
Bostrichidae			6	.14
Curculionidae			138	3.3
Tenebrionidae			208	5
Unidentified				
Coleoptera			246	5.9
Lepidoptera	480	76.8	1784	43.4
Hymenoptera				
Combined	257	41.4	235	5.7
Formicidae			137	3.3
Unidentified				
Hymenoptera			98	2.3
Hemiptera				
Combined	7	1.1	8	.19
Cicadidae			7	.17
Unidentified				
Hemiptera			1	.02
Totals	625		4104	

Table 7: Means (with standard error) and percentages of the six most frequent orders of arthropods in burrowing owl pellets.

	Total #Individ.	Total Pellets	# Pellets with	% pellets with	Mean per total pellet	Total Burrows	# burrows with	Mean per burrow
Coleoptera	1006	625	508	0.812	1.609± 0.14	290	221	4.552 ± 0.36
Lepidoptera	1784	625	480	0.768	2.744± 0.526	290	201	8.876 ± 0.98
Solifugae	714	625	372	0.595	1.142± 0.12	290	152	4.644 ± 0.39
Orthoptera	237	625	282	0.451	0.379± 0.1	290	101	2.346 ± 0.59
Hymenoptera	235	625	257	0.411	0.376± 0.07	290	91	2.582 ± 0.48
Scorpiones	120	625	196	0.313	0.192	290	64	1.875 ± 0.20

Homogeneity of Proportions and Marascuilo Pairwise Comparison

The proportions of the prey animals were significantly different; Chi-square = 666.11, df = 5, $p < 0.05$. Table 8 shows the results for the Marascuilo Pair-wise Comparison. The only groups that did not show significant difference from one another were the Coleoptera vs. Lepidoptera and the Orthoptera vs. Hymenoptera. Solifuges had significantly higher proportions in the diet of burrowing owls than orthopterans, hymenopterans and scorpions.

Table 8: Marascuilo comparisons. C=Coleoptera, L=Lepidoptera, S=Solifugae, O=Orthoptera, H=Hymenoptera, Sc=Scorpiones, *= no significant difference.

Contrast	Value	Critical Range
C – L	.044*	.076
C – S	.217	.083
C – O	.361	.084
C – H	.401	.083
C – Sc	.499	.081
L – S	.173	.086
L – O	.317	.087
L – H	.357	.086
L – Sc	.455	.083
S – O	.144	.093
S – H	.184	.092
S – Sc	.282	.090
O – H	.04*	.093
O – Sc	.138	.091
H – Sc	.098	.090

DISCUSSION

Feeding Study

Several studies have shown that solifuges will refuse prey that possess toxins or repugnatory chemicals, such as stink bugs, hairy caterpillars, coccinellid larvae, blister beetles, millipedes, velvet ants, and scorpions (Muma 1966b; Punzo 1993, 1994b). However, three of the solifuges in this study repeatedly ate toxic prey, especially the *Danaus* pupae and polydesmid millipedes. All of the millipedes consumed were eaten head first, and only the first four segments after the head were consumed. Polydesmid millipedes have glands attached to their spiracles starting on the fifth segment and extending to the rear of the body. Only the larger solifuges ate the millipedes, but each ate them in the same manner. This could point to learned behavior, or it could simply be size related; only larger solifuges have the strength to overcome the armored plates of a flat millipede. However it could also be simple selective ingestion, as exhibited by other

solifuges during feeding observations (Punzo 1998) where they will choose sections of prey that are less sclerotized, or in this case, not chemically defended. Additional studies are needed to determine whether solifuges will routinely attack and at least partially consume suitably-sized toxic prey.

In this study, solifuges were better able to handle and eat toxic prey than hard prey as demonstrated by the odds ratio estimate (Table 5) where the probability of eating toxic food was .72 as compared to the probability of eating hard food at .28. Although the odds ratio estimate suggests a preference for toxic over hard prey items in this study, the number of solifuges responding to test items was small (with only 3 solifuges eating hard or toxic prey), yielding a large variance for the analysis; hence, a lack of statistical significance and a need for cautious interpretation of the results. The variance of the odds ratio between hard and toxic prey that determined preference is too large for this inference to be anything more than a conservative observation.

After encounters with the extremely aggressive *Pachycondyla* ants, four solifuges died before reaching the last termite fed at the end of the night. Several solifuges attempted to eat the ants, but only two succeeded. The ants were an interesting prey item, since it became apparent throughout the course of the study that while toxic, they also had extremely hard exoskeletons. A large *Z. fordi* female that ate an ant made continuous attempts to kill the ant throughout the 10-minute feeding bout and was bitten and stung repeatedly. Once the solifuge had the ant in her chelicerae, it took her five minutes to separate the abdomen from the rest of the ant's body. She ate the entire ant, two more prey items throughout the duration of the study and went on to eat repeatedly

after the study had concluded. Throughout the course of the study, this solifuge was offered 6 hard and 6 toxic prey and ate 5 of each, and ate all 18 of the termites offered her. The other two solifuges that accepted food during the study were both offered 5 hard prey items and 5 toxic items over the course of the study. Each ate all 5 of the toxic prey offered, but only a small percentage of the hard prey items.

Even without statistical analysis, it is possible to see that solifuges were better able to handle and eat toxic prey than hard prey (Table 2). Behavioral observations made during this study seemed also to confirm that size plays a role in ability to handle hard prey. In addition to the three solifuges that ate prey regularly, five others attempted to eat hard prey, but failed. Most notably, a mature female *B. velox velox*, attemped on two occasions to eat the *Tenebrio* beetles that were roughly her size, by hanging on to the joint between the prothorax and the mesothorax and continuously chewing on the elytra. In the end, however, she failed to crack through the exoskeleton. The unidentified tenebrionids beetles provided a more difficult challenge to all sizes of solifuge. This may be due to the amount of time investment needed to deal with hard beetles (Wharton, 1987). Even the large female *Z. fordi*, that ate nearly every prey item offered to her, gave up on the first unidentified beetle she was offered, after 7 minutes of repeated and constant attempts to crack through the fused elytra. She was the only solifuge of the three that ate hard or toxic prey that eventually ingested these beetles, although the other two tried repeatedly to eat them. She was offered a total of 3 of the unidentified beetles, and was able, after her first attempt, to eat the other two. This may indicate the ability to learn from previous encounters.

There have been some questions as to whether or not mature male solifuges feed. Previous workers have hypothesized that mature males during mating season may not feed (Muma, 1966b) and have used only mature females in feeding studies because of the possibility that males are unlikely to feed (Punzo, 1993, 1998). One of the three solifuges that ate regularly during the study was a mature *Zeria fordi* male. He ate a total of 7 prey items: 2 *Tenebrio* adults, 1 *Danaus* pupae, 2 *Pachycondyla* and 2 polydesmids.

A high percentage of solifuges died throughout the study and a large number of solifuges that normally ate their termites refused other prey throughout the course of the study. Refusal of prey in laboratory or captive settings has been observed during previous experiments and is not unusual (Muma 1966b). Solifuges are difficult to keep in captive environments and are prone to stress in caged conditions (Muma 1967; Punzo 1998; Cloudsley-Thompson 1977). During this study, solifuges died due to stress or being overpowered by the ants offered in the feeding trials. Two solifuges escaped their enclosures overnight. Because so many of the solifuges died during the last three days of the study, only the first three days of the study were compared during analysis. In the future, a larger number of solifuges will be necessary for more rigorous quantitative analyses.

The results from this study serve to confirm Muma's (1966b) findings that solifuges readily accepted termites in caged conditions, as sixteen of the seventeen solifuges in this study ate termites repeatedly. Whether or not the solifuge species used in this study prey on them regularly under natural conditions is not known. Mostly,

however, the results from this study were in contrast to previous reports of feeding behavior in solifuges, especially with regard to solifuges eating toxic prey. Punzo (1994a/b) reported that solifuges consistently rejected velvet ants (Mutillidae) which are aggressive and possess venom, while two different solifuges, both *Z. fordi*, ate the aggressive and chemically protected *Pachycondyla* ants during this study, with the male eating three. In Punzo's study, solifuges did not eat millipedes, whereas in this study that was not the case at all. The fact that solifuges in this study not only ate toxic prey, ate them repeatedly provides new information on the range of capabilities of solifuge feeding. *Zeria fordi* was the only species of solifuge that ate toxic prey, whereas all the others ate termites at one point or another throughout the study. This may point to a unique ability among *Z. fordi* to handle toxins, or may simply be attributed to the fact that *Z. fordi* is a much larger species than the others in the study, and is therefore able to overtake the aggressive animals like the ants and the larger animals like the millipedes, and that the toxins of the pupae were not of sufficient quantity to harm the solifuges. The ability to eat toxic prey shown in this study, may also be attributed to locality. For example, if a solifuge lives in a habitat with many toxic prey, they may learn how to properly handle them in order ingest them. Future studies may show that solifuges that regularly encounter toxic species in the wild may be better able to prey upon them, whereas if a solifuge has a great deal of variety in the vicinity, it may choose to go after less toxic prey. This could be tested for *Z. fordi* as a future study, with simple preference trials between toxic and no-toxic prey. However, the foraging behavior of solifuges, in

which chance encounter is a dominant factor, suggests that choosing between alternative prey may rarely be an option.

In terms of useful qualitative data, this study provides some interesting observations, mostly with regard to solifuges repeatedly displaying the same feeding behavior when eating millipedes. Observations under natural circumstances are needed to support findings in the lab, but the fact that three different solifuges (of the same species, *Z. fordi*) handled and ingested the millipedes in exactly the same way suggests that it was not their first encounter with these abundant animals.

In terms of quantitative analysis, this study tested several species of solifuge at once, whereas research in the past has focused on a single species' feeding habits. Even though the analysis was hindered somewhat by the small sample size, it does contribute to and elaborate upon known solifuge feeding behaviors, but as with most everything in solifuge biology, may provide more questions than answers at this point.

Burrowing Owl Study

Some similarities exist between prey composition in this study and previous studies on burrowing owls. In this study, Lepidoptera larvae were clearly the most abundant individual items in the owl diet, however, beetles were represented in more burrows. This corresponds with findings from pellet analyses on burrowing owls in Chile (Schlatter et al. 1980). Most of the beetles found in the pellets were Scarabaeidae and Carabidae, both ground dwelling families. Since burrowing owls live in terrestrial burrows, it makes sense that a large portion of their arthropod diets would be made up of ground-dwelling arthropods. One of the scarabs, *Oxygrylius ruginasus* Leconte, 1856,

could be identified to species because of a distinctive morphological feature of the labrum. However, little is known of this species ecology, so further inferences about its relationship with burrowing owls cannot be drawn.

One difference between the study of Schlatter et al. (1980) and this study, is that the majority of orthopteran prey in pellets in Chile were crickets rather than grasshoppers. In this study, and in others mentioned by Schlatter et al. (1980) from North America, grasshoppers are the most numerous representative of the orthopterans. This could be an example of prey localization and distribution, and further studies on South American burrowing owls are needed to see if owls in other parts of South America have similar feeding patterns.

This is the first study to show that solifuges are a major portion of some burrowing owls diets. The fact that solifuges account for 17.3% of overall arthropod prey as the third most frequent prey item, means that burrowing owls are capable of handling fast-moving prey in addition to relatively slow-moving arthropods like scarabs and caterpillars. The majority of pellets dissected in the study were collected from late spring to early fall (May-September), which encompasses the time period of greatest activity for solifuges (June, July and August) in North America (Muma 1974a/b).

While this is the first study to show that burrowing owls in the desert rely on solifuges for a regular portion of their diet, it is not surprising when you look at diet accounts of other small desert owls. When comparing the diets of the little owl in extremely arid ecosystems to more mesic habitats in Europe, Obuch & Kristin (2004) determined that the desert little owls were more dependent on specifically eudominant

animals like solifuges and scorpions. An arid or semi-arid habitat will most likely be the link for bird predation on solifuges across the world. Of course, these are the dominant habitat types for solifuges (with a notable exception being the rainforest dwelling *Dinorhax*). Arid areas close to the equator may see year-long predation on solifuges by birds of prey, while more arid regions at higher latitudes may show a more seasonal dependence on solifuges as prey.

There seems to be some discrepancy on the feeding ecology of burrowing owls with respect to diel activity. Burrowing owls have been reported on different occasions to be nocturnal, diurnal and crepuscular feeders, depending on the area they inhabit (Thomsen 1971; Rich & Trentledge 1983; Coulombe 1971). The burrowing owls in this study are most likely crepuscular or nocturnal, judging from the solifuges found in the pellets. Eremobatidae and Ammotrechidae are the only solifuges found in the southwestern United States and most solifuges in North America are nocturnal, with the exception of two genera (Muma 1966c; Cloudsley-Thompson 1977).

The large number of larval lepidopteran mandibles may be the result of a seasonal hatch of caterpillars tied to specific host plants near burrows. Other burrowing owl workers have suggested that food caching takes place and that a mass emergence of prey may attract burrowing owls for either food caching away from burrows or stockpiles within burrows. This was the case with a pair of burrowing owls during the breeding season in south-central Idaho, where the pair had several caches of long-horned beetles (Rich & Trentledge, 1983). However, without further identification of the larvae found in this study, this is sheer speculation.

Differences in prey preference over the course of a season for burrowing owls have been noted (Scott, 1940) and it has been attributed to seasonal variation in prey availability; either due to rapid growth from larval to adult stages or short seasonal adaptability on the part of the invertebrate prey. Local differences in prey abundance may explain why burrowing owls in previous North American studies have not shown preference for solifuges. For example, burrowing owls on the California coast may not have the same opportunity to feed on solifuges that burrowing owls in the desert southwest would; solifuges were not included in the extensive diet of owls at the Oakland airport at the edge of San Francisco Bay (Thomsen 1971). Also, there are some burrowing owls, from regions of North America in the US and Canada, that need to migrate to escape harsh winters, whereas the burrowing owls of the southwestern US are non-migratory (Thomsen 1971). These major differences between populations of burrowing owls account for the varied results of previous prey studies. Schlatter et al. (1980) reported that it is likely that burrowing owls do not actively search for invertebrate prey, but rather are opportunistic, eating only what is readily available in the area at the time. It is this line of thinking that supports the hypothesis that during certain seasons, when populations of solifuges are at their peak, solifuges could become important prey for any insectivorous birds in the area. Since solifuges are not poisonous (see discussion below), they make for a relatively easy, albeit fast-moving, target. Similarly, but on a larger scale, owls and other birds of prey may show evidence of adaptive biologies among different habitat types, such as prairies, grasslands and hot, arid areas, which is the case in elf owls (*Micrathene whitneyi* Cooper, 1861).

Since there are reports of other birds eating solifuges in Africa, as mentioned earlier, it is easy to assume that with further investigation, the diets of birds in desert regions worldwide, will show at least some reliance on solifuges. The question of seasonal prey selection is still new when it comes to solifuges, but as more information is gathered about these arachnids, more trophic interactions will be uncovered.

Seasonality

Critical examination of seasonal patterns of dietary preferences may prove that solifuges are important sources of food during the dry season in arid ecosystems around the world. This will be a monumental undertaking, due to the complexities of omnivory at the predator level and the variations in solifuge seasonal patterns the world over. For example, Muma (1974a/b?) found that adult solifuges in North America are most active during the summer months of May-August, with only a handful of species active in March, April, September and October and no species active during the remaining months. This makes sense when taking into account North American winters. However, solifuges found closer to the equator are known to have less specific seasonal patterns as a result of stable temperatures and may respond to wet/dry seasons instead. In Africa in particular this may have a significant effect on seasonal availability of solifuges as prey. Bat-eared fox (*Otocyon megalotis*) have been shown to eat solifuges in both the wet and dry seasons in Kalahari Gemsbok National Park (Nell, 1978). In July and December 1976, both dry months in the Kalahari, bat-eared foxes were recorded to have eaten a total of 22 solifuges. However, in only one month during the wet season, January 1977, the foxes ate 15 solifuges. This could be a result of higher abundance of adult solifuges

during the wet season as a response to higher food availability. Seasonality may be the link between solifuges and the complexities of seasonal and opportunistic omnivory in desert food webs.

Additional Observations

Several additional, non-quantitative observations were made during collection of solifuges in Kenya for the distribution and diversity study. In May 2006, a lilac-breasted roller (*Coracias caudatus* Linnaeus, 1776) and a white-browed sparrow weaver (*Plocepasser mahali* Smith, 1836) were both observed attacking a clear plastic cage that was holding an active solifuge; at one point the sparrow-weaver grabbed a leg through the slatted top of the cage. The roller is an insectivore, but adult sparrow-weavers are granivorous and only feed insects to their young (Crook 1964). This is not the first time that seed-eating birds have been observed to prey on solifuges. Willoughby (1971) also recorded spike-heeled larks and gray's larks which are insectivorous birds, feeding on solifuges but also recorded a granivorous lark, stark's lark (*Eremalauda starki* Shelley, 1902) eating solifuges. Wharton (1980) also recorded stark's lark jumping up on bushes to eat insects and one stole and ate solifuges from terraria in his laboratory. Many seed-eating birds may supplement their diets in response to seasonal fluxes in food availability, and closer examination of diet studies of individual species in Africa may provide more clues as to whether or not solifuge predation is a common occurrence in such birds.

Solifuge remains retrieved from the stomach of an *Agama agama* Linnaeus, 1758 lizard near Kora National Reserve were located during this study in NMK holdings. As

noted in the introduction, most reports on African reptiles as predators of solifuges are unpublished or anecdotal. The report on the stomach contents of a species in the gecko genus *Pachydactylus* Weigmann, 1834 by Haacke (1976) is thus an exception.

Scorpion and solifuge intraguild predation is a popular anecdotal tale cited by arachnid enthusiasts to enhance the perceived perniciousness of solifuges in the wild. Under natural circumstances it is not clear if these animals consistently encounter each other, however during data collection for this survey, several study sites in Kenya contained both scorpions and solifuges, often in shallow burrows under neighboring rocks. Intraguild predation of solifuges does occur, however, as Wharton (1980, 1987) recorded predation on solifuges by spiders on two different occasions.

Solifuges as Predators and Prey

When examining the data presented and compiled in this study, we can make some predictions about which additional animals in arid and semi-arid environments may prey on solifuges, to create a more complete picture of solifuges in desert trophic systems. Several small felines, mongooses, and animals in the family Viverridae have been shown to eat solifuges in southern Africa (Table 9). Table 10 shows small mammals that are likely to prey on solifuges on the continent of Africa, judging from similar biologies and ecologies to animals known to eat solifuges. Looking at Smithers (1971) data, several assumptions can be made, not just about small mammals in Africa, but also for the rest of the world where solifuges are found. It is predicted that small terrestrial carnivores, like canids and felines, and omnivorous animals like mustelids and viverrids are likely to eat solifuges on a regular basis. Similarly, species that are

described as arboreal in nature, but that forage on the ground for insects could opportunistically feed on solifuges. Also, with the incredible diversity of desert rodents, there are likely hundreds of small mammals in the world's arid areas that forage on solifuges, either as seasonal or year-round prey. In North America, coyote (*Canis latrans* Say, 1823), foxes, weasels and rodents are just a few of the animals that could rely on solifuges seasonally for nourishment.

Table 9: African small mammals reported to eat solifuges. (Quantifications in right column provided from Smithers (1971), with percent of stomachs reported to contain solifuges.)

Bat-eared fox	Smithers, 1971; Bothma 1966	6/50 – .12
Aardwolf (Proteles cristalus Sparrman, 1783)	Smithers, 1971	traces of solifuges
Wildcat (Felis lybica Forster, 1780)	Smithers, 1971	14/80 – 0.175
Serval (Felis serval Schreber, 1776)	Smithers, 1971	1/3 – 0.33
Black-foot cat (Felis nigripes Burcell, 1824)	Smithers, 1971	2/5 – 0.40
Cape fox (Vulpes chama Smith 1833)	Smithers, 1971	6/23 – 0.26
Black-backed jackal	Smithers, 1971; Stuart, 1976	10/59 – 0.16
African civet	Smithers, 1971; Bothma, 1971	1/3 – 0.33
Small-spotted genet (Gennetta genetta pulchra Matschie, 1902)	Smithers, 1971	18/78 – 0.23
Rusty-spotted genet (Genetta tigrina rubiginosa Pucheran, 1855)	Smithers, 1971	5/30 – 0.16
Selous mongoose (Paracynichis selousi ngamiensis deWinton, 1896)	Smithers, 1971	8/36 – 0.22
Yellow mongoose (Cynictis penicillata Cuvier, 1829)	Smithers, 1971	2/50 – 0.04
Banded mongoose (Mungos mungo Gmelin, 1788)	Smithers, 1971	1/4 – 0.25
Dwarf mongoose (Helogale paruula Sundevall, 1847)	Smithers, 1971	1/21 – 0.05
Common genet	Viljoen & Davis 1973	-

Table 10: Examples of African small mammals likely to prey on solifuges.

Honey badger	(Millivora capensis Schreber, 1776)
Striped Polecat	(Ictonyx striatus Hollister, 1915)
Small Grey mongoose	(Galerella pulverulenta Wagner, 1839)
White-tailed mongoose	(Ichneumia albicauda Cuvier, 1829)
Large Grey mongoose	(Herpestes ichneumon St-Hilaire, 1818)
Slender mongoose	(Galerella sanguinea Ruppell, 1836)
Suricate	(Suricata suricatta Schreber, 1776)
Large spotted Genet	(Genetta tigrina Schreber, 1776)
African Hedgehogs	(Atelerix spp. Wagner, 1841)
Side-striped jackal	(Canis adustus Sundevall, 1847)
Golden jackal	(Canis aureus Linnaeus, 1758)
African palm civet	(Nandinia binotata Gray, 1830)

At this time, there are no records for small primates eating solifuges in Africa. However, it is noted in many separate diet surveys that several species supplement their diets with arthropods foraged from the ground (Hamilton et al. 1978) and further investigation may uncover solifuges in the diets of such animals as vervet monkeys (*Cercopithecus aethiops* Linnaeus, 1758) and baboons (*Papio* Erxleben, 1777).

The mammal literature might also help to provide a focus for future surveys of hard to find or poorly known solifuges. For example, data from fecal samples of termitophilous mammals in Africa, like aardvarks, aardwolves and pangolins, may provide important clues as to the biology of the Rhagodidae and certain daesiids, like the aforementioned *Hemiblossia* spp., which are believed to be termitophilous in their own right. The heavily sclerotized heads of both adult ants and termites pass through the intestinal tracts of aardvarks, making for relatively easy identification from fecal samples (Taylor et al. 2002). Thus, any solifuges in the diet should be similarly easy to detect. While solifuges are likely not the target of termitophilous mammals, since they prefer similarly sized prey (Redford 1987), these animals may inadvertently ingest

solifuges that hide in termite mounds. Since the cheliceral remains of solifuges have been found from scat analysis of animals like aardwolves (Smithers 1971), this could give solifuge workers a starting point for taxa that have proven difficult to collect.

Diets of predatory birds may be linked to age and experience, with younger birds ingesting more invertebrates while they are learning to hunt and older birds taking on more challenging prey. Prey movement, particularly fast and aberrant behaviors, coupled with a predator's familiarity with prey species may have an impact on which species are more heavily preyed upon than others and solifuges fit such movement descriptions (Wharton 1987). Also, raptors have been shown to exhibit reversed sexual dimorphism in size, with the females being slightly larger, and this may also have an effect on the ability of raptors to seize prey depending on agility and speed (Newton 1979). Because of this, we would expect to see solifuges in diets of smaller birds and males more often than adult females in many raptors, due to their smaller size and increased agility.

Are Solifuges Poisonous?

There is no question as to the efficacy of solifuges as predators, but the mechanisms behind their success remain in question. Obuch & Kristin (2004) reported that little owls in their study ate poisonous solifuges. Several morphological studies have been conducted on solifuges from different parts of the world and only one has concluded that there may be a possible venom gland in the chelicerae (Aruchami & Sundara Rajulu 1978). They tested the venom from *Rhagodhima nigrocincta* Bernard, 1893 (identified in the paper as *Rhagodes nigrocinctus*) from Tamil Nadu in

southeastern India, on lizards. Taking glandular tissue from the chelicerae and injecting it into the lizards resulted in 7 out of 10 lizards becoming temporarily paralyzed, as compared to no paralyzations from non-glandular tissue. Venom was concluded to have a trace amount of 5-Hydroxytryptamine which is also found in some scorpions and wasps. This is an interesting find, because most solifuges are found not to possess venom. More studies are needed to conclude whether or not certain families or genera may have evolved the use of venom for prey-capture and defense. Numerous anecdotal tales of painful swelling and loss of localized feeling in the area of a bite have been reported since the early 1800s, while several of my fellow solifuge specialists have been gnawed on repeatedly with no ill effects. Although one species of solifuge appears to be venomous, we cannot say that the Solifugae as a group are venomous.

Solifuges and Desert Trophic Systems

Desert trophic systems seem simple but omnivory and seasonal fluctuations in food availability make them extremely complex. Polis (1991) estimates that all species eat and are eaten by between 10^1 and 10^3 species in desert trophic interactions. Because of the large number of potential interactions, inadequate numbers and compilations of diet data for different levels of food webs become problematic for single species pictures. He uses the example of man-hours in the field while observing prey items of the scorpion *Paruroctonus mesaensis* Stanhke, 1957 in the Coachella Valley in southern California. In five years and over 2,000 hours in the field, the limits of the diet were never reached, providing some clue as the incredible work and time involved in creating a complete picture of the diets of dominant species. Solifuges are no exception. For one

thing, solifuges may eat different prey throughout their lifetime in relation to their size, as evidenced by the few feeding studies completed thus far. Also, there can be little to no generalizations when talking of the 'diets of solifuges.' Even though solifuges have a world-wide distribution, their varied habitat use and specializations in micro-habitats means their predators and prey across and between habitats will be equally varied. The cannibalistic tendencies found in solifuge feeding habits are not uncommon in the larger scheme of desert food webs. Polis (1991) hypothesized that "looping" and cannibalism are exhibited by over 1300 species in deserts. Age-structure plays a large role in solifuge cannibalism, especially for second-instar intraspecific competition (Muma 1966b), but it has been noted that adult solifuges that encounter each other may fight, and the victor often eats the other. Cannibalism associated with mating also occurs, and has been documented before, during and after mating in *Eremobates* spp. (Muma 1966b).

Future Work

These studies provide much needed baseline data that will support future work on the placement and importance of solifuge arachnids in desert trophic interactions. In the future, it will become necessary to compile and more rigorously assess qualitative and observational data from past literature to create a complete picture of the trophic value of solifuges in desert communities.

From the few studies done on solifuge feeding behavior and preliminary compilation of data on solifuge predators, it is clear that whenever solifuges are present in an ecosystem, they are an important part of the trophic dynamics on both a micro and

a macro-level. They are voracious predators of a wide variety of arthropods and are able to eat some chemically-protected and toxic arthropods that are difficult for other animals. The complexities of cannibalism and intraguild predation create possibilities for unique horizontal trophic interactions with spiders and scorpions. Finally, the number of different vertebrates that have been recorded to eat solifuges suggests that with further investigation, we may be able to quantify their role as an important food source in arid ecosystems, or at the very least, that solifuges are of supplemental significance as a seasonal resource.

CHAPTER IV

OUTREACH IN THE FACE OF STUDENT APATHY

INTRODUCTION

As a student, a teacher and an informal educator, I understand the greatest affliction facing education today. It's not drugs, it's not alcohol, and it's not the social hierarchy in schools. It's apathy and it affects almost every student at one point or another. Kutcy & Schulz (2006) targeted many different reasons for student apathy in K-12, including lack of parental support, disrespect for the teacher's role, focus on extra-curricular activities like sports, and a school system in need of serious change. In addition, students generally don't enjoy the learning process and have no idea how to connect the subjects to a career track they will enjoy that fits their interests. To add to the problem, challenges associated with K-12 student apathy are often looked at as separate from problems facing undergraduates across the country. This view, that you can talk about one, without looking at the other, is a serious misstep toward solving what some have called an educational crisis.

The consequences of grade-school apathy become readily apparent in the early years of undergraduate education. Instead of applying themselves in a field they feel is exciting, students find themselves, especially in the first two years of undergraduate work, floundering to find *something* to major in. Nearly two-thirds of undergraduates change majors at least once before graduation (Tobash 2005). When I started teaching at the college level as a graduate teaching assistant I was shocked that so many students

who had made a conscious choice to attend college had little to no interest in their classes. But I realized quickly that the reasons for attending college are different than they were a decade ago when I enrolled. The parties and yearning for independence are still the same but undergraduate education is not a choice anymore, not a privilege for those who have worked hard and made clear decisions to study in a particular field. A degree means higher pay, which everyone wants. It's less of a rite of passage and more of an expectation. Quite frankly, students feel obligated to go to college; as obligated as they did to go to grade school. In our society, a person is looked down upon if they do not have a degree, but most students do not want to be in school, and so the problem of apathy recycles each year.

Apathy is almost always written about from a teachers' perspective. "How do we motivate them? What's wrong with them? We weren't like that!" I believe, however, if teachers honestly remembered themselves as students they would be able to dredge up a few memories of being frustrated with the learning process. For example, I pride myself on being an incredibly focused individual, excited and hyper-passionate about learning. This is not to say that I am above feeling apathetic toward school. Usually I feel apathy, and often resentment, due to teachers who are inadequate, or who I perceive to be burdened by the task of teaching. Students can tell when a teacher doesn't want to be there and vice versa. Teachers are sick of dealing with blank-faced pupils, and it's easier for students, especially teenagers, to 'check-out' than to invest in a class where they can't see how it connects to their lives. This just reinforces a cycle of apathy that continues until graduation. I'm sure John Dewey did not intend for the motto of public

education to read, ‘Thank goodness that’s over,’ but unfortunately that’s how most students feel.

During the past two years, while completing my research on solifuges and teaching different labs as a graduate teaching assistant, I have also focused on building an outreach resume. This makes me a student, a teacher and an informal educator all at once. This may be the only time in my life when I will play these three roles simultaneously, and from this unique perspective I have been able to learn a lot about the struggles students face in modern educational institutions, the trials and tribulations of teaching, and the importance of informal outreach education to pick up the slack and bridge those two areas.

I am of the firm opinion that everyone wants to learn. We just want to learn about subjects that interest us, that are in some way connected to our lives. We also want to learn in a way that is fun, so that learning is a positive experience, instead of a chore. It is this belief that has helped to shape my outreach work. I’m an entomological outreach specialist, so I teach about insects. When I started teaching people about bugs four years ago it felt impossible. Nobody wants to learn about bugs. Most people despise them and feel a sense of fear and confusion about bugs that is almost debilitating. By defining this common denominator, I hit on an overarching theme that forms the basis of my teaching style, no matter what the subject. I target apathy indirectly by talking about common fears and students don’t even realize they are learning because they are busy talking about themselves. By providing students with a personal platform, they are automatically engaged. Because my teaching style is

informal, it has allowed me to work in a variety of settings like in-class workshops, integrated media formats and museums exhibits.

WORKSHOPS

I have created 'bug' workshops to combat stigmas and prejudices held by many young people about arthropods. My arthropod workshops can be adapted to any age audience, but mainly target K-12 and the freshmen/sophomore years of undergraduate work. The arthropod workshops I have developed have a dual focus depending on the audience. One objective is to teach children and young adults about the arthropods in their immediate environment, while educating about safety and health issues of certain arthropods. By doing so, fear of these animals will be changed into a healthy respect and understanding of their habits and behaviors. The second objective is to link fear of arthropods (an overarching theme in most young people) with social and personal issues they face on a day-to-day basis. I use fear of arthropods as a vehicle to talk about everything from prejudice and racism to career development to educational potential. In this way, youth will be better prepared and more driven to excel in their classes as well as better able to deal with fear both in social situations, school, and the workplace. I discourage hand-raising and speaking-in-turn especially in small groups, and encourage the students to talk to each other about specific encounters with the arthropod kind, positive and negative. By the end of the workshops, they have created a dialogue, not just with each other, but also with themselves, and in the process learned about

arthropods without even realizing it. This is a new and innovative approach for confronting common problems facing youth the world over.

My arthropod workshops have been brought into classrooms as enrichment programs that parallel biology curricula, for Earth Week celebrations and cultural enrichment seminars. I have taught workshops for students from south-central Los Angeles, where African-American, Latino, Asian and White students are in constant battle over social control of their schools. In the Eastern Sierra Region of California I have taught a different mix of students about the same principles. I have also taught my workshops to over a thousand students in rural Kenya, in the northern rift valley near Lake Bogoria. In Kenya, where prejudice and racism is not the main social problem (though tribalism exists and has been a focus in our workshops), the workshops center around career development. Fear is the basis of prejudice, racism, and stalled career development, and it is fear that prevents young people from reaching their full potential.

During the workshops I use a combination of different techniques like interaction, peer-teaching, local language/vernacular use, hands-on contact and collection activities. Initially, I get the students involved by asking their opinions on insects and spiders, then addressing each individual's concerns or ideas. In doing so, class participation is encouraged and critical thinking about the specific roles particular 'scary' arthropods play in the environment. Beyond simply identifying bugs as *creepy* or *gross* I encourage students to talk about specific qualities in the bugs that evoke emotion. Common answers include: "I think it's going to bite me…I hate how many legs it has… I only hate the hairy ones," etc. We talk as a group about each comment, and I explain

the science behind such characteristics. Also, I encourage a dialogue between and among students and teachers about local insects and the ecosystems to which they are associated. In Kenya, specifically, I use local languages to connect with the students. I mix Kiswahili and colloquial greetings with English as a way to breach the barrier that tends to exist between teachers and students. Where appropriate, I use local slang used by the children themselves, to forge an immediate bond. Often, I will ask the students how to best say something, or the names of certain animals in Kiswahili and their vernacular language. This further blurs the lines between teacher and student, and gives the students a sense of accomplishment and responsibility not often associated with traditional 'lecture-style' teaching. Instead of passive recipients of information, the students become one half of a conversation about arthropods, their misconceptions and their conservation.

To encourage interaction in the classrooms, live arthropods are used in the workshops. Students are allowed to hold benign arthropods and then I have them talk to the class about the experience. This way, the students become the teachers and in doing so, take charge of their own education for the day. In turn, their peers are challenged to engage positively in the experience, and want also to hold the animals. Venomous or toxic animals are observed safely, while the curriculum centers on the key characteristics that make those bugs identifiable in the field. Students become better able to distinguish between harmful and beneficial bugs, and learn why venomous and toxic animals display certain threatening behaviors. The students are then able to modify their behavior to prevent personal injury while still respecting the animal in its habitat.

At the end of each workshop, I lead students and their teachers outside on the grounds of the school to look for arthropods. This provides another hands-on learning opportunity, and also reinforces some of the facts learned during the lecture component. Students further confront their fears and learn to observe threatening animals from a safe distance, without endangering themselves or the animals. Some students enjoy this part of the workshop so much they start their own bug collections.

I have found that the teaching techniques I use in my workshops easily translate to the university setting. Recently, I had the opportunity to teach several laboratory sections of ENTO 201, Entomology for Non-majors, as a graduate teaching assistant at Texas A&M University. The course also doubles as an introductory course for entomology majors and is a major recruiting class for the department of entomology. I didn't want the students to simply memorize facts to regurgitate on a test, I wanted the students to leave the class with an appreciation for arthropods, and understand the enthusiasm I feel for them. By incorporating teaching techniques from my workshops, and involving the students as teachers in their own right, I was able to crack through the general malaise felt by many teachers of introductory classes. In the classroom I try to engage every student individually, find their strengths, likes and dislikes, and capitalize on them as best I can. For example, if one student is exceptionally good at dissecting, but uncomfortable identifying the parts, I pair that student with someone who is good at identification. Then I ask them to teach everyone else on an individual basis about the tricks of dissection and what to look for on the insect. Every other student comes and sits with the pair and looks through the now communal microscope. This increases the

confidence level for everyone in the class, to be able to replicate what they have seen. In addition, once students feel that you understand their individual interests, they feel more comfortable asking for help when they need it and explaining why they are having trouble.

There is a great deal of talk in education lately about creating a 'community environment' in the classroom, a safe place for ideas, a collective conscience. This is a great idea, but I feel teachers try to create this classroom environment in the wrong way. The moment you tell a class that you want a community in the room, you've lost them. The concept is too abstract. It becomes yet another assignment, or worse still, they perceive it as a horrible place where they'll be forced to talk about their feelings in front of the class. This is certainly the way I perceive it. A community environment comes naturally from interactions between the students, with the teacher as facilitator. I often push students to talk to one another; a quiet classroom for me is a dead classroom. When I first started teaching, I was amazed at the reluctance on the part of the students to engage with one another. Moreover, I learned something that was startling; with regard to educational maturity, there is really no difference between high school juniors and seniors and university freshman and sophomores. It makes sense if you think about it, but this is a fact that is ignored by many university professors, either from being so far removed from their own educational experiences that they have forgotten, or having experienced a different level of education when they were in high school. By using peer teaching techniques and teaching students on an individual basis while encouraging interaction, I feel I have been largely successful in fighting apathy at the college level.

VIDEOS

We're never going to get kids away from the television. Teachers have been battling it for years and we are losing on all sides. We are not more interesting than television and while being entertaining is helpful in the classroom, it is not in our job description as teachers to constantly fight for their attention. Since television is not going away any time soon, we should use it to our advantage. Integrating science and technology and using technology as a teaching tool is one way that I engage students. For the past two years, I have spent my summers working for the University of California's Natural Reserve System at the Sierra Nevada Aquatic Research Laboratory and the Valentine Eastern Sierra Reserve. As a teacher for the Outdoor Science Education Program, I was given free reign to create a 2-week class for ten middle school children. Most of these children had grown up taking these classes and were in the market for something new. I decided to combine an insect identification and ecology class with a video production class. All of the students learned to use a digital video camera and digital still cameras, mastered sound and light production methods, video editing techniques, and post-production graphics. Each student was also involved in the research for the documentary, including writing the script, studying the target insects, responsible collection techniques for different kinds of arthropods and finding suitable filming locations. Students learned about the production process from scripting and storyboarding to filming and on-screen etiquette, to editing and post-production details.

The classes were a challenge for the students. They had to work together as a democracy to create a film they would all be proud of. When one student was a director

for the day, the others had to listen or lose their opportunity for future leadership. By allowing the students to take responsibility for the final product, they had a vested interest in creating quality work. Since we had such a small time frame in which to finish the film, any conflicts posed a major threat to the completion of the movie, and it was in this tense atmosphere where students learned the difference between positive and negative confrontations. For the first time in their lives, they could see that apathy not only hampered their experience on a personal level, but also seriously impeded the group's ability to work toward a common goal.

Deciding how content should be delivered was also a major hurdle for the groups. Since the short films were about the lives of different insects at the reserves, and other children would be seeing the videos, the idea of scientific accountability was important to discuss. The students were asked to teach in the way they would want to learn while still staying true to the facts about the insects. The kid-generated content that resulted was full of fun facts, laughter, and hands-on experiments and often mimicked what they were watching on television (A-1: Thatch.mov).

This style of teaching and integrating science and technology was so successful that I am now working with 4-H's Junior Master Gardener Program (JMG) to create a video camp tour of the United States, where kid-videos are posted online so that students across the country can learn from one another while having similar experiences.

COLLABORATION

Outreach education on a small, intimate scale is incredibly effective, but it only serves a limited number of people. Collaboration is necessary to strengthen community ties and stimulate new opportunities, and creating relationships with larger institutions that can reach varied audiences is important for the sustainability of outreach projects. Because of this, I have made it a point to make connections with several established institutions and organizations, so that my outreach efforts reach more people. These institutions and organizations include, but are not limited to the National Museums of Kenya, Rescue Dada School for Girls, the Terrestrial Invertebrate Taxon Advisory Group from the American Zoological Association, the Lake Bogoria National Reserve's Dryland Environmental Education Center in Kenya, and the Kenya Wildlife Service (KWS).

During my time in Kenya conducting research on solifuge arachnids, I worked with several different institutions to provide arthropod outreach. Since I am affiliated with the National Museums of Kenya for research on solifuges, the opportunities for outreach that connect with a large audience were almost endless. While finalizing my research permits, I organized and implemented the renovation of a live animal exhibit for the NMK's Nairobi Snake Park. *Wadudu Wazimu* (Crazy Bugs) focuses on the importance of arthropods in different ecosystems. Audio push buttons were installed, delivering arthropod facts in both English and Kiswahili (A-2: Herbivores.mp3, audio file example). Several rehabilitated street children from the Rescue Dad School helped to paint a large mural displaying different arthropods found in Kenya for Girls (A-3a/b:

picture). The exhibit is now the first ever interactive museum exhibit in East and Central Africa, and has been met with much excitement by the school groups that visit the park. This was made possible by a grant from the American Zoo and Aquarium Association's Terrestrial Invertebrate Taxon Advisory Group (A-4: picture).

In terms of solifuge research, a more indirect outreach project has been undertaken. Each park that allowed our entry where solifuges were collected will receive an informational poster on the solifuges found there. The Kenya Wildlife Service (KWS) will hang our informational posters in their visitor's centers. These centers serve tourists, locals, KWS staff and thousands of schoolchildren each year.

A great deal of my five months in Kenya was spent in and around the Lake Bogoria National Reserve. When testing pilot in-class workshops, I partnered with the Lake Bogoria National Reserve's Dry-land Environmental Education Center, founded by the World Wildlife Fund. During my time in Bogoria, I taught a total of 12 workshops to over a thousand students in primary and secondary schools in the area (A-5a/b: picture). Because of the success of the workshops, further collaboration is planned. I am currently in talks with the World Wildlife Fund to provide these workshops to seven different areas in Kenya (A-6: Kenya Files.mov, workshop proposal sample video).

CONCLUSION

We are, essentially the sum of our experiences. A teacher at my high school once told me that I had no aptitude for science, even though I would spend hours by myself in the library learning about animals. As a result I was not accepted into the marine biology class that I had wanted so desperately to take. I was told to stick to what I was good at: dance and drama. I went on to receive a B.F.A in Acting and subsequently returned to school, because my desire to study animals was so strong. Now, years later, a masters candidate and a teacher in my own right, I understand what incredible power a teacher wields over young minds. Perhaps apathy is the result of the fear that no one will take you seriously, or that you won't be good enough even if you try.

Even though I wonder who I would be now, if that teacher back in high school had let me into the marine biology class, I don't dwell for long. I would never trade the winding road that led me to this point in my career. It has made me a better student, a better teacher, and an educator more willing to take risks.

CHAPTER V

CONCLUSION

The results presented in this thesis contribute to the already incredible knowledge of Kenyan fauna, and allow for a more complete picture of the diversity, distribution and feeding ecology of solifuges in the region of East Africa. One objective of this study was to determine whether or not Kenya is an important overlapping ground for the northern and southern African solifuge families. While the extent of the overlap still requires more investigation, Kenya does present itself as a country with diversity beyond that originally thought. Because of political and social unrest, typically in the extreme northern and eastern regions, there are large portions of Kenya's most arid lands that remain unexplored when it comes to arthropods. Since several new species, and additional genus and species records for the country were discovered during this short survey (the genus record from the extreme north), it is reasonable to assume that more discoveries in Kenya are likely.

Areas of specific interest in this study included the area around Lokichoggio in the northwest of Kenya, the Mara ecosystem, the Tsavo region and the area around Lake Bogoria. The new genus record for the country, *Tarabulida*, was discovered in Lokichoggio, along with un-described species of Rhagodidae, and was the only region during this survey where all five families found in Kenya were shown to co-exist, using a combination of new data and museum records. This survey provides the first records for solifuges in the Mara ecosystem, and some of the only records of Rhagodidae in the

NMK holdings come from the Tsavo area in southeastern Kenya. During this survey, the area around the Lake Bogoria National Reserve was particularly productive, with numerous solifuges collected during each of the three separate trips to the area. Most exciting for the area are plans to include solifuges in the reserve's management plan, which includes outreach education and protection.

Outreach, especially in underserved parts of the world, can be a bridge between scientific research and the public. Since solifuges are widely regarded as dangerous to people and are reviled in Kenya, a little education can go along way toward protecting these animals. A major goal of my time in graduate school, in addition to fulfilling the requirements of a thesis, was to find a way to simultaneously create outreach opportunities that could be carried on beyond my school career. My focus on arthropod outreach during this survey succeeded in creating future opportunities for collaboration in Kenya and other parts of East Africa.

It is incredibly important to focus attention on lesser-known arachnids (Harvey 2002b) not just from a biodiversity standpoint, but also from a public perception standpoint. If we can separate fact from fiction about animals that are widely misunderstood and therefore persecuted and relay these facts to the general public, then we can hope for a future that includes conservation of special invertebrates like solifuges.

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APPENDIX A

Several multimedia components accompany this thesis as files available for downloading:

A-1: Thatch.mov is a movie created with children from the University of California.

A-2: Herbivores.mp3 is an audio file as part of an exhibit for NMK.

A-3a/b: These are .jpeg images that accompany the exhibit for NMK.

A-4: This is a .jpeg image that accompanies the exhibit at NMK.

A-5a/b: These are .jpeg images associated with workshops.

A-6: Kenya files.mov is a movie of workshops events in Kenya.

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